MAPS

AND

MAP-MAKING

E. A. REEVES, F.R.G.S.

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THREE LECTURES DELIVERED UNDER THE AUSPICES OF THE ROYAL GEOGRAPHICAL SOCIETY

BY

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PREFACE

THESE three lectures were delivered for the Royal Geographical Society in the theatre of the Civil Service Commissioners on March 5th, 12th, and 19th, 1909, and with the exception of occasional amplifications which have been considered advisable, no change has been made in them. Most of the illustrations, diagrams, and maps with which they are now accompanied were shown as lantern slides when the lectures were given. No attempt has been made at anything approaching a treatise or text-book on the subject, and what is stated here must be considered as of a general introductory nature only. However, it is hoped that the lectures may prove of some educational value, and for this reason the Council have agreed to publish them.

In addition to the lantern slides, the interest in these lectures was considerably increased by the exhibition of old and new instruments, and examples of British and foreign cartographical productions of various dates and styles, which were shown on screens round the Hall. It has been found possible to give reproductions of some of these in the text, and at the end is given, as an example, a map published last year in the *Geographical*

Journal, showing the results of the Uganda-Congo Boundary Survey, under the command of Lieut.-Colonel R. G. T. Bright, C.M.G. Many valuable instruments were lent for the first lecture, and I should like to place on record my gratitude to all who assisted in this matter, specially to Sir Clements Markham, K.C.B., F.R.S., Capt. D. Wilson Barker, R.N.R., Capt. W. F. Caborne, C.B., R.N.R., the Royal United Service Institution, Mr. S. A. Ionides, Messrs. Cary & Porter, and Messrs. Casella & Co.

E. A. REEVES.

CONTENTS

I

II

III

LIST OF MAPS, ILLUSTRATIONS, AND DIAGRAMS

COLOURED MAPS

MAPS AND MAP-MAKING

I

PRELIMINARY REMARKS, AND HISTORY AND DEVELOPMENT OF THE MORE IMPORTANT SURVEYING INSTRUMENTS

WHATEVER may be in store for man in the future, it is certain that for the time being his sphere of activity is, as regards his bodily presence, restricted to the outside shell of one of the smaller planets of the solar system—a system which after all is probably by no means the largest in the vast universe of space. He may soar in his imagination, and by the intellect with which he is endowed, be able to investigate, with more or less certainty, domains far removed from the restricted area to which he is confined; but as regards his actual presence, he cannot leave for more than an insignificant number of feet, the outside crust of this small earth upon which he has been born, and which has formed in the past, and must still form, the theatre upon which his activities are displayed.

The connection between man and his immediate terrestrial surroundings is therefore very intimate, and the configuration of the surface features of the earth would thus naturally soon attract his attention. It is only reasonable to suppose that, even in the most remote ages of the history of the human race, attempts were made, however crude they may have been, to depict these in some rough manner; and possibly, to begin with, the representation of hills, rivers and plains was scratched upon the

sides of rocks and cave dwellings by our primitive forefathers, much in the same way that a child commences to draw, or the native Tahitian, at the present day untouched by civilization, constructs a rough relief map of his islands by pieces of wood, like that shown in Fig. 1; or the aboriginal inhabitant of the remote Marshall Islands in the Pacific, attempts to make a chart of his native group by bamboos (see Fig. 2). The Eskimos again are noted for their intuitive skill in map-making, and Fig. 3 is a copy of a part of a map of the west coast of Greenland, drawn by one of these remarkable inhabitants of the far north from his own knowledge, and from that gathered from other natives on board H.M.S. *Assistance* during the winter of 1850–51. The outer line shows the same coast-line as properly laid down on our Admiralty chart, and you will see that the general resemblance is remarkable.

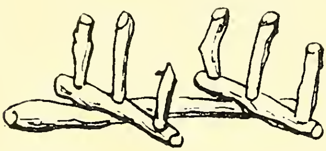


Fig. 1.—Tahitian Relief Map.

(*From Moseley's 'Notes by a Naturalist on the Challenger.'*)

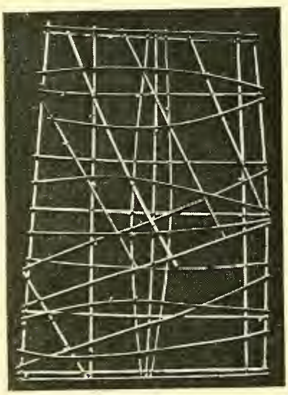


Fig. 2.—Marshall Islanders' Chart.

(*From reproduction in 'Man' of chart in British Museum.*)

If we only knew the truth, it is quite possible that maps and plans of some sort or other were drawn long before we have any record of them. We can imagine boundary questions arising even in very early days, although most likely no prolonged diplomatic discussions were required for their adjustment, but much more rough and ready means employed. As populations increased and congregated in special areas, plans and maps became a necessity; the limits of individual property had to be defined as now,

and evidence of this has been brought to light by researches in Egypt, Mesopotamia, and elsewhere. For the allotment of lands and mines, marking out of boundaries, location of wells, plans would be almost a necessity, and would naturally be constructed with the very dawn of civilization. There is in the British Museum a plan of the city of Susa, of the Bible, which is at least as old as the seventh century B.C. Still earlier maps are in existence, of which the plan preserved in the Museum of Cairo is one of the most interesting. This shows the basin of Lake Moeris on the Nile, with its canal and the position of towns upon its borders, with notes giving information concerning these places. But one of the oldest maps known is preserved at Turin, and represents the Wadi Alaiki where the Nubean Gold Mines were situated. This appears to be most

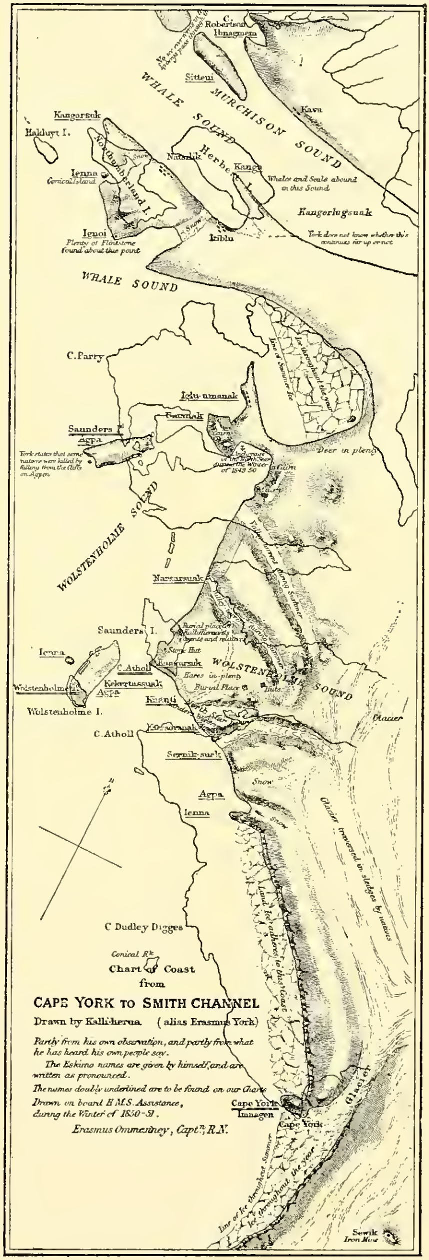


FIG. 3.—Eskimo Map.

complete in its way, and as these mines were worked in the time of Rameses II., it is probable that the map dates back to about B.C. 1370.

It is reasonable to imagine that the earliest of cartographical representations would consist of maps and plans of comparatively small areas, produced to meet some demand of the times, and it would only be later on, in more advanced conditions, that any attempt would be made at geographical generalization.

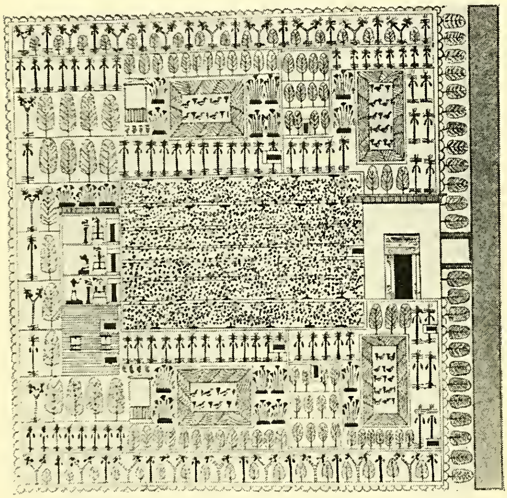


FIG. 4.—Plan of Ancient Egyptian Villa.

In the early days of the world's history, map-making, like every other science or art, was in its infancy, and probably the first attempts of the kind were not what we should now call plans or maps at all, but rough perspective representations of districts or sketches with hills, forests, lakes, etc., all shown as they would appear to a person on the earth's surface; and, after all, this was only natural. To represent these features in plan form, with the eye vertically over the various objects, although of very early origin, was most likely a later development, but who first started the idea we are never likely to know now, and as we have already seen, it dates back far into antiquity. The plan shown in Fig. 4 is of an Egyptian nobleman's villa, taken from a Theban tomb of the 18th Dynasty, and given in Maspero's 'Dawn of Civilization.' This must have

been constructed more than three thousand years ago, and, as will be seen, is partly a plan and partly a perspective view.

Geography is many sided, and has numerous branches and divisions; and if it be true that map-making is not the whole of geography, as cartographers and surveyors do well to remind themselves occasionally, it is at any rate a very important part of it, and is in fact the foundation upon which all other branches must necessarily depend. If we would study the structure, or geomorphology, of any region we must have a good map of the region upon which the various land-forms can be shown. If we desire to represent the distribution of races of mankind, or any other natural phenomenon, it is essential first of all to construct a reliable map to show their location. For navigation, for military operations, charts, plans and maps are indispensable, as they are also for the demarcation of boundaries, land taxation, and many other purposes.

The relative importance of mathematical geography, as that branch of the subject is generally called which includes the basis of map-making and the mathematics that pertain to it, is, I think, well shown in the diagram in Dr. Mill's 'International Geography,' where you see it is placed at the base of the great pyramid of geographical science.

In these short lectures I propose to deal with the subject of 'Maps and Map-making,' in the three natural divisions in which it appears to me to fall. All maps are, or at least are supposed to be, based upon some kind of survey, and for any surveying, instruments for exact measurement are essential; therefore reversing this order, I will first attempt a brief account of surveying instruments, tracing their history and development from the earliest forms to those with which we are familiar at the present day. The next lecture will be devoted to a general consideration of the

various methods of geographical surveying; and finally, in the third we will deal with the actual construction of maps themselves.

History and Development of Surveying Instruments

So far as we can tell, the earliest of all instruments, if instrument it may be called, was the *Gnomon*, which afterwards developed into the sundial. This, in its earliest form, consisted of an upright rod, and was used for roughly determining time and the distance of any place from the equator, or the latitude.

At the summer solstice, when the sun reached its greatest northerly declination, at any place under the tropic of Cancer the sun would be vertical at noon, and no shadow would be cast, hence the distance from the equator to the place where no shadow was cast was the same as the declination of the sun, or $23\frac{1}{2}°$ N. The distance to any place North or South of this position of the earth could then be computed by the length of shadow cast by the Gnomon. The invention of the Gnomon is often ascribed to Anaximander, who was born B.C. 612, and to whom is generally ascribed the first map of the world; but the Gnomon is known to have been in use among the Chaldæans long before this time, and all he did was probably to introduce it into Greece.

The Gnomon received a most important improvement at the hands of Aristarchus, by which the angular altitude was given directly without any computation. He substituted for the plane a hemispherical bowl, and placed in its lowest interior point a peg or rod equal in length to the radius, and perpendicular to the plane to which the bowl was attached. The concentric equidistant circles or semicircles drawn on the inside surface of the bowl, formed a scale on which

the sun's altitude was measured from its shadow. This arrangement (Fig. 5) was called a *Scaph* (Greek *σκάπτω*, to dig), because of its shape, and is important, as it is the forerunner of angle-measuring instruments with a graduated circle. The Gnomon, which now generally assumed the form of the Scaph, but often retained its old name, was used to determine the latitude of a place. On the equinoctial day the noon sun casts no shadow at the equator, hence the angular measure of the sun's shadow at any other point on this day, when the sun is on the meridian, will be the latitude. Pytheas, the discoverer of Britain about B.C. 330, in preparation for his voyage to our shores, sailed from Phocæa to Massalia (Marseilles), and fixed the latitude of this latter place by means of a large gnomon divided into 120 parts, with a result that seems almost incredibly accurate, for, adding the sun's semidiameter which he omitted, the latitude he obtained differs not more than one minute from the true latitude of Marseilles Observatory. For the latitudes for the rest of his voyage he depended upon the oldest of all known methods, that is the comparative lengths of the days.

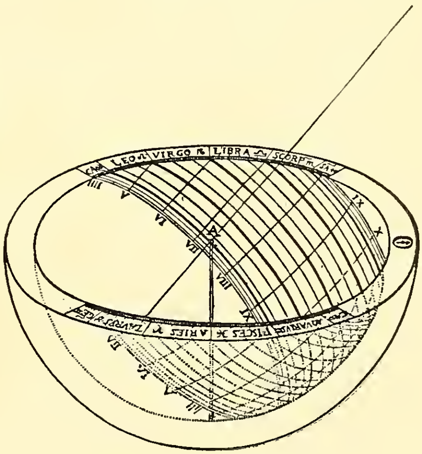


FIG. 5.—The Scaph.
(*From Laussedet's 'Recherches sur les Instruments,' etc.*)

Perhaps the most famous of all the old instruments is the *Astrolabe*, the invention of which is ascribed to Hipparchus about B.C. 150, and which was afterwards developed by Ptolemy, A.D. 130, by Arabian and Persian astronomers, and others as time passed on. It continued

in use up to the sixteenth or seventeenth century in some form or another, to be only finally superseded by the quadrant and sextant in the eighteenth century.

The Astrolabe (Figs. 6 and 7) consisted of a somewhat heavy circular metal ring with inlet plates and discs for different latitudes, from 4 to 7 inches or more in diameter. It could be suspended from the thumb so that the instrument should fall in a vertical position. On the back was a number

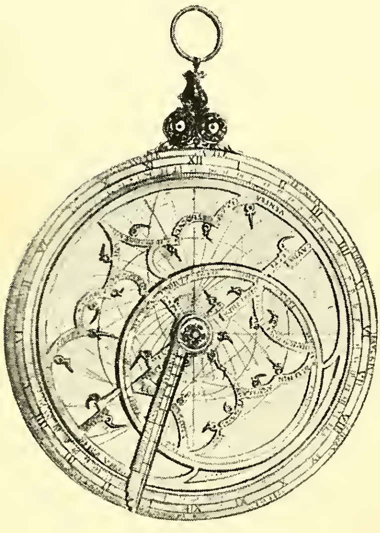


Fig. 6.—Astrolabe (front).

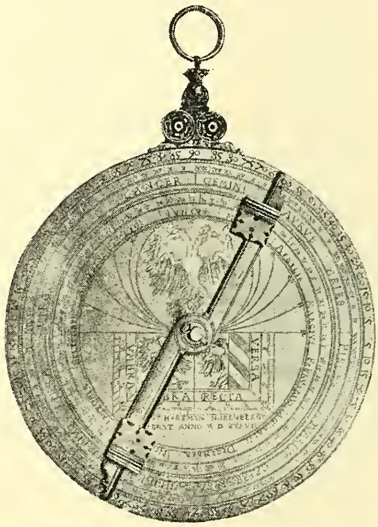


Fig. 7.—Astrolabe (back).

of concentric rings marked with various divisions. These rings were generally circles of degrees; circles of the signs of the Zodiac; circles of the days of the year and their numbers; circles of the months with their days, and numbers of the days; and lastly, circles of Saints' days with their Sunday letters. Within all these were the scales of Umbra Recta and Umbra Versa, each of which was divided into twelve parts for the convenience of taking and

computing heights and distances of points by an approximate method which has long been superseded by trigonometry. In taking altitudes the Astrolabe was suspended by the ring, with a rule or alidade sighted at the object observed, when the altitude would be read off the outer circle. The Umbra Recta and Umbra Versa scales were, as stated, used for the determination of heights and distances of terrestrial points. This was done by sighting on to the top of, say a tower, of which the height was required. The rule would then cut the Umbra Recta divisions at a certain figure which we will suppose to be 8 ; then the distance from the observer to the tower, multiplied by 12 and divided by 8, was considered the height of the tower. The numbers roughly correspond to the natural tangents for the Umbra Versa, and cotangents for the Umbra Recta, of the angles indicated by the alidade, multiplied by twelve. As the divisions on the lines were equal, the result cannot have been more than approximate, but for small angles, the error was not great. Many other problems were solved, or attempted to be solved, by this wonderful old instrument, and in fact, in those days the learned philosopher was a bolder man than his average representative at the present time ; for not only could he give you heights, distances, latitudes, time, and all sorts of such like useful information from his instrument, but he went much further, and could tell you, or was supposed to tell you, a good deal about your future prospects in life, as shown by the astrological houses, of which the surveyor of the present day has, I fear, lost the art.

The *Diopter* seems to have been another wonderful old instrument ; but I am sorry to say we have no very exact account of it. The sketch (Fig. 8) is taken from a reconstruction given in Colonel Laussedet's most useful work, 'Recherches sur les Instruments,' etc., to which I am indebted for several of the drawings of old instruments here reproduced.

If this representation can be relied on, it appears to have been a sort of prototype of the theodolite, and all that would be necessary would be to add graduated vertical and horizontal circles to make it a passable instrument of modern date. It is, however, unlikely that it ever possessed these circles, and it was principally used for marking off similar angles, by which means a great deal of the earliest land-surveying was carried on. The stand was rendered vertical by means of a plumb-line instead of a spirit-level, and stood upon a small tripod. By means of the screw arrangements it was possible to turn the sides

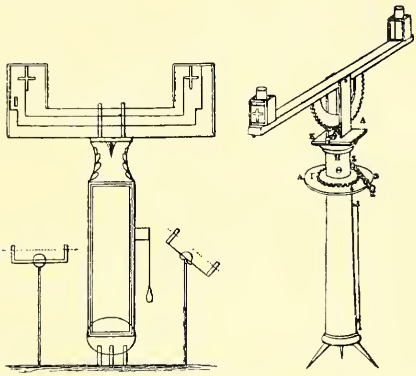


Fig. 8.—The Diopter.

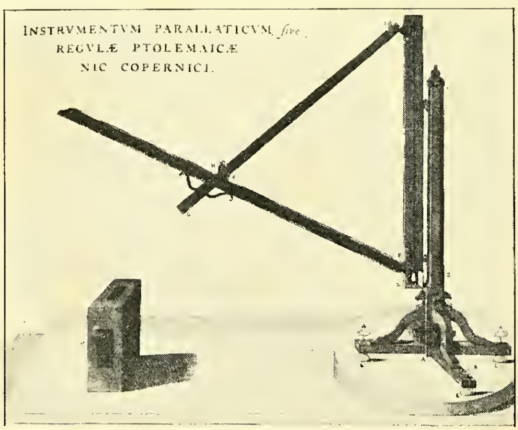


Fig. 9.—Ptolemy's Rods, or Triquetum.
(*From Bleau's Atlas.*)

both vertically and horizontally. Hero of Alexandria wrote a treatise on the Diopter, and a form of this instrument was used by Hipparchus.

Fig. 9 represents another interesting and ingenious old instrument, known as *Ptolemy's Rods*, or the Triquetum, which continued for many years to do very creditable work. This instrument consisted of three rulers, one of which was held vertical, another directed towards the object whose zenith distance was to be measured, whilst the third gave the distance between fixed points on the other two. The angular zenith distance was then taken from a table, or computed from the lengths of the rods. This instrument is specially interesting, not only because it was used by

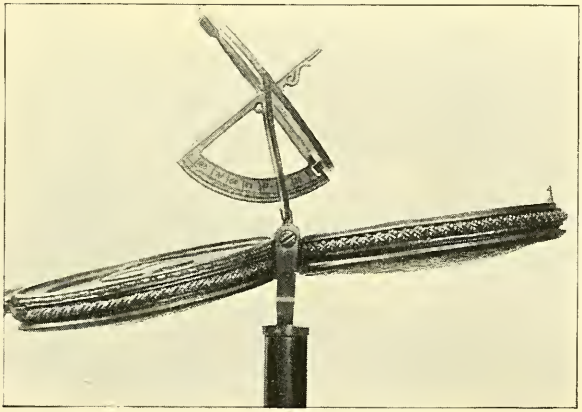


FIG. 10.—Drake's Astrolabe.

Copernicus in his observation of planets, but because it is a prototype of many topographical instruments where three rulers are employed for obtaining heights and distances. A few years ago a range-finder was submitted for my inspection, which was almost exactly this instrument, held horizontally.

From the early dawn of maritime enterprise instruments for measuring altitudes and angular distances on board ship have naturally been considered of the greatest importance, and whilst, as we have seen, the astrolabe held the chief

place for sea observation for centuries, and in fact, continued in use until the sixteenth or seventeenth century, there were doubtless many attempts at improvements as time passed, and voyages of greater length were undertaken. Sometimes the astrolabe was combined with a sundial, as shown in Fig. 10, which is a photograph of the famous Drake astrolabe from the Museum at Greenwich. Instead

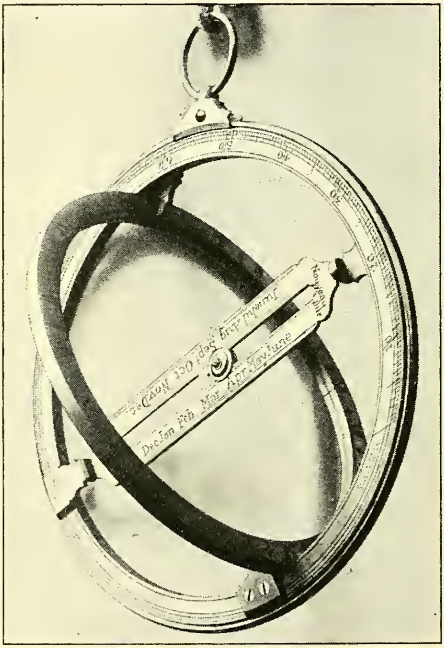


FIG. 11.—Oughtred's Horological Ring.

of the ordinary astrolabe with all its elaborate circles and curves, for navigation purposes the instrument became much simplified, and we have here a view (Fig. 11) of an ingenious arrangement called Oughtred's Horological Ring, which can be used for taking altitudes, finding latitude, and also as a sundial.

The difficulty of course has always been to find some method of measuring angular altitudes on the rolling deck

of a vessel. The astrolabe furnished a rough means of doing this, and it is indeed remarkable what results were obtained with it. Instead of a complete circle such as that of an astrolabe, sometimes a *quadrant* with a plumb-line was used, as shown in Fig. 12, which is from 'The Workes of Edmund Gunter, containing the description of the Sector, Cross-staff, and other instruments,' etc., published in 1653.

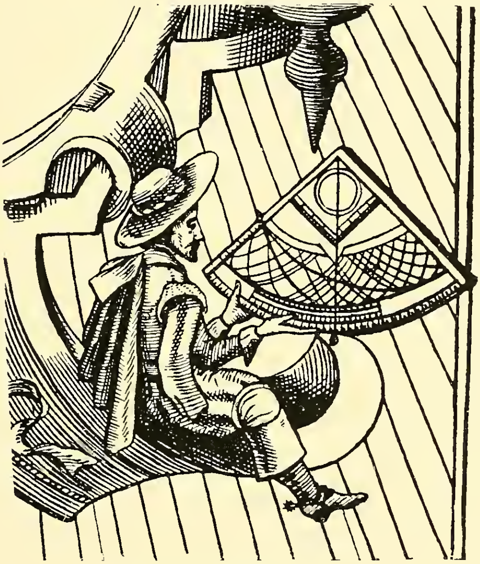


FIG. 12.—The Quadrant.

A step forward was made in the construction of instruments for mariners when the *Cross-staff* appeared, for here we have the first attempt at an instrument by which the heavenly body and the horizon line could be seen at the same time. The earliest known description of the Cross-staff is by Levi ben Gerson, a Babylonian Jew, in A.D. 1342, but whether he was really the inventor of it appears to be uncertain. Whoever the inventor was his memory deserves to be honoured, as he struck out quite a new and more

satisfactory line in the construction of instruments for sea use. We will now glance at one or two representations of the early forms of the Cross-staff. The first one (Fig. 13) is from Peter Goos' 'Sea-Mirror,' of 1658, and is interesting from the attempt the author has made to show the method of observation; although it need not necessarily be supposed that the observer really had to stand waist-deep in the sea to take the observation. The next Cross-staff (Fig. 14) is from John Davis' 'Seamen's Secrets,' of 1594.

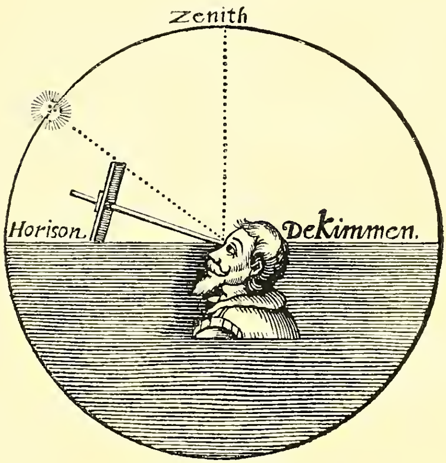


FIG. 13.—Cross-staff.

The Cross-staff consisted, as its name suggests, of a staff of wood, upon which were made to slide one or more cross pieces. The staff was graduated, and the cross pieces could be moved along it until, looking through the sight near the eye, they would be seen to cover the two objects between which the angle was to be measured, which was then read off the graduation. In taking an altitude, the staff was held with the sights vertical, the lower ends being made to cut the horizon, whilst the upper just covered the sun. This instrument could only be used

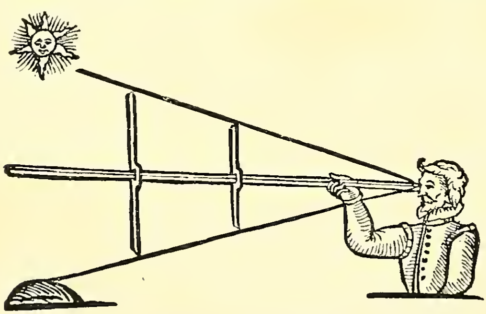


FIG. 14.—Cross-staff.

for observing the sun when the eye was protected by some kind of shield, and it was principally for this reason that it was later on superseded by the *Back-staff* (Fig. 15).

The Back-staff was invented by Captain John Davis, the famous old Arctic navigator, about 1594. It was given this name, as the observer, in taking the altitude, turned his back to the sun. It consisted of a combination of two arcs, or a chord and an arc, upon each of which was a movable sight. The sight on the small arc was set to any convenient angle, say 30° or 60°, and then, with his back to the sun,

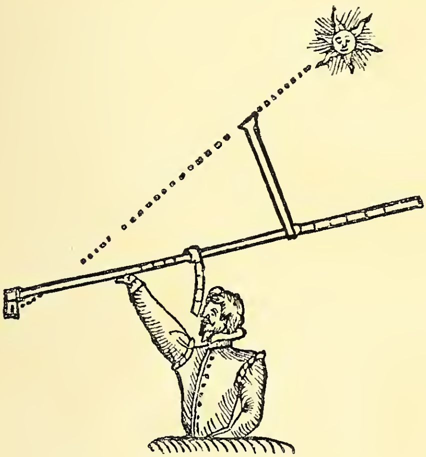


Fig. 15.—Davis' Back-staff.

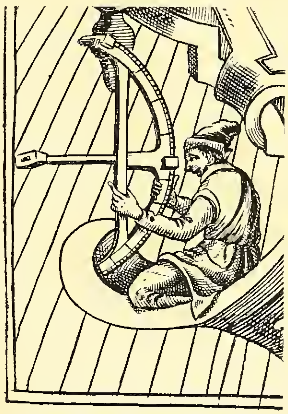


Fig. 16.—Cross-bow.

the observer looked through the lower arc at the horizon line, and at the same time adjusted the sight until he saw the sun's rays through the sight on the upper arc cutting the horizon line at the same time. This was certainly a most ingenious device, and one that was calculated to give better results than any before. The modification of it, known as Davis' quadrant, was generally used at sea for many years.

Another interesting old seventeenth-century instrument was the *Cross-bow*, which was a modification of Davis'

Back-staff. The sketch of it (Fig. 16) is taken from Edmund Gunter's work of 1653, and from this we can obtain a general idea of its form and manner of use. Although cumbersome and somewhat grotesque in appearance, this instrument had its advantages, and Gunter, in his work, gives at considerable length the method of using it. It consisted of a large graduated arc, and a long central sighting arrangement; movable sights could be placed in any desired position on the arc. In finding latitude, one sight, the upper one, was set to the declination, and then, as with the Back-staff, with his back to the sun on the meridian, the observer moved the other sight until the horizon line was seen, while at the same time the sun's rays passed through the upper sight. The latitude could then be read off at once, although the result must necessarily have been very rough. Any altitude could be measured with this instrument by viewing the horizon line with one sight and the heavenly body with the other.

In use about this date were several other old instruments that deserve to be mentioned, such as the *Meteoroscope*, a kind of Armillary sphere, and the *Nocturnal*, an instrument for ascertaining the hours of the night by observing the Pole Star and other circum-polar stars; but these never came into general favour.

Of the many attempts that have been made to fit a quadrant or sextant with an artificial horizon, so that altitudes of the sun or stars can be taken when the natural horizon line is obscured, that shown in Fig. 17 is perhaps the earliest. It is taken from the *Transactions of the Royal Society* for 1732 (Vol. 37), and represents a devise by Mr. John Elton, whereby a small level bubble was fitted to the vernier arm, or *index*, as he calls it, of a Back-staff, so that when the natural horizon was invisible, all that the sailor had to do was to hold the instrument

with his back to the sun so that the rays of light passed in the ordinary way through the upper lens or sight, and then move the index arm until the level was seen to be approximately in the centre of its run, when the reading on the arc would be the altitude. The lantern was for lighting the sights when observing at night. From trials made at sea the resulting altitude was found to differ from those made with a Davis Back-staff with the natural horizon, from 1′ in favourable circumstances, to about 25′ in a rough

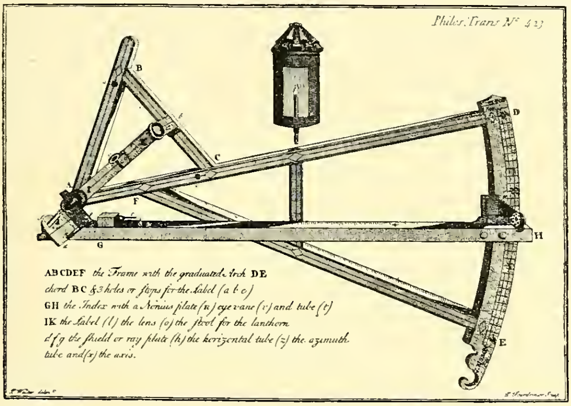


FIG. 17.—Elton's Artificial Horizon fitted to Back-staff.

sea. Elton's own account of his invention, which is published with the sketch, is most interesting. Since that date many such attempts have been made, including Commander Becher's and Admiral Beechey's artificial horizons, Admiral Fleuriais' gyroscopic horizon, Captain Gadsden's fork pendulum arrangement, and, last of all, a devise of my own which I brought out only last year, and which is shown in Fig. 18. The pendulum with the mirror is reversed after each altitude is taken, and the mean of any pair of readings is taken as correct. None of these can give more than approximate results at sea, and the primary object I had in view when constructing the latter was to furnish an artificial horizon

for land exploration which should be more portable and convenient than the usual mercurial forms. It will also, I

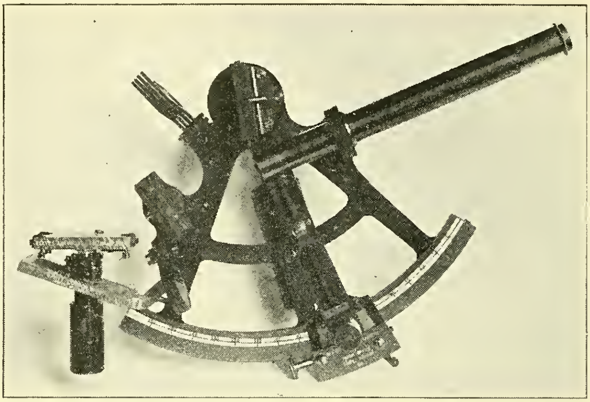


FIG. 18.—Reeves' Artificial Horizon fitted to Sextant.

hope, be useful in Polar work, on moving ice, and perhaps also at sea under favourable conditions.

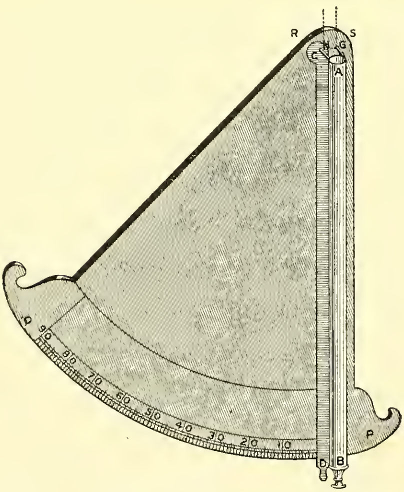


FIG. 19.—Newton's Reflecting Octant.

We now come to an epoch-making change in the construction of instruments for navigation, and that is the introduction of the reflecting mirrors in the quadrant. The original suggestion of an instrument for measuring angles between two objects by reflection, so that the eye should see both objects superimposed upon each other at the same time, seems to have occurred to Dr. Hook, about 1664; but Sir Isaac Newton was doubtless the first to show how an instrument for mariners

could be made on this principle. Although the honour of doing this is generally thought to belong to John Hadley, the fact is, Sir Isaac Newton, in 1700, in a letter to Halley, the Astronomer Royal, described most minutely an instru-

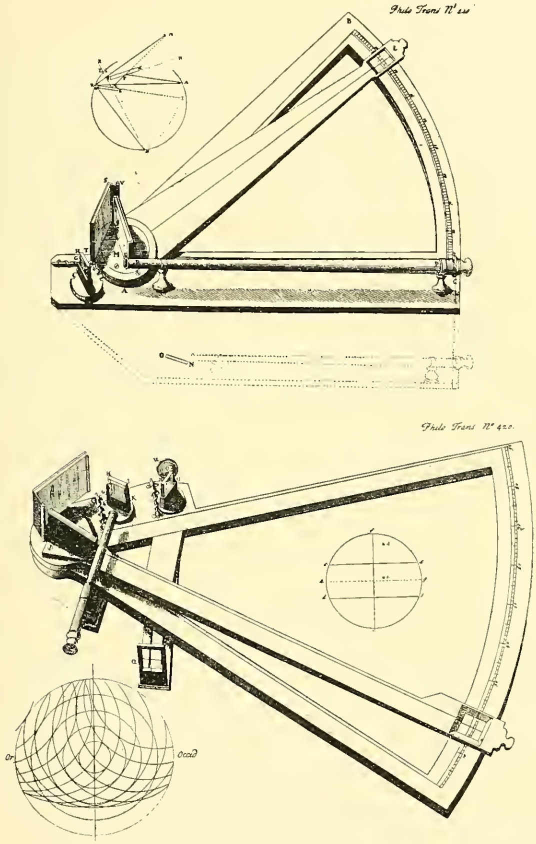


Fig. 20.—Hadley's Octant.

ment which has certainly the right to be called the first reflecting instrument on the principle of the sextant. But for some unexplained reason, the letter was never made public during Halley's lifetime, and it was only after his death that it was found among his papers, and in

1742 published in volume 42 of the *Philosophical Transactions of the Royal Society*. Fig. 19 is from the sketch given in this volume with the important letter. The existence of Newton's invention was doubtless unknown to John Hadley, who was one of the vice-presidents of the Royal Society, and presented a description of an instrument of his own design to that Society in 1731. Hadley's octant was in many respects an improvement on Newton's, and it will be seen that his invention, shown (Fig. 20), is pretty much the same as the instrument used to-day. The telescope was introduced, and this must have made a tremendous difference in the accuracy of the readings. Fig. 20 is from the plates in Hadley's own description of the instrument, and the volume containing them is well worth careful perusal. As its name suggests, the octant consisted of an eighth part of a circle, and by double reflection measured angles up to 90°. Another old octant, without a telescope, is shown in Fig. 21. A further improvement was soon introduced when the first sextant was constructed by Adams, to the design of Captain Campbell, in 1757 (Fig. 22), and since then, no material change has taken place in the construction of these most important instruments. The latest pattern sextant, by Cary, is shown in Fig. 23, and it will be seen that it is in all its main features the same as that of Campbell, made over 150 years ago.

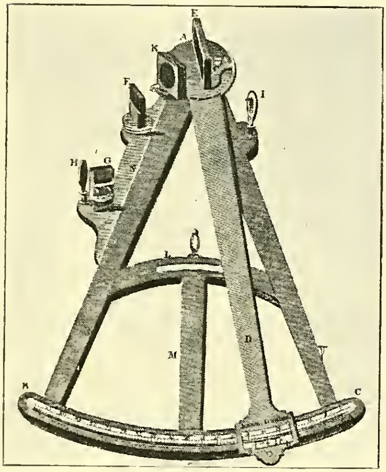


Fig. 21.—Octant.

Another form of this class of instrument is the Reflecting Circle, which was introduced first of all by the German

Tobias Mayer in 1767. His idea was that by having a complete circle, and by repeating the readings in various parts of the arc and then dividing the total sum by the

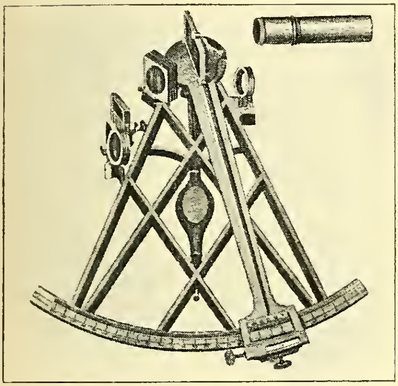


Fig. 22.—Campbell's Sextant.

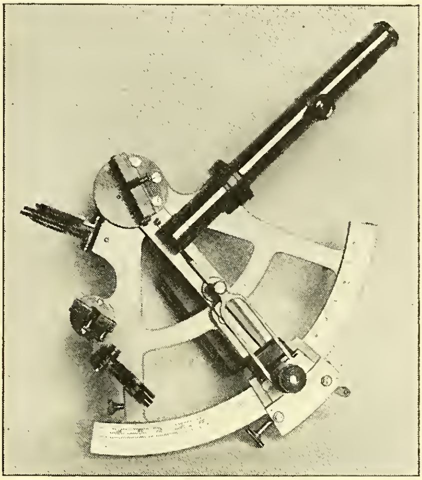


Fig. 23.—Modern Sextant.

number of readings, errors in centring and graduation would be eliminated. A better form of reflecting circle was designed by Borda, in France, in 1775 (Fig. 24), and this, with few modifications, has been extensively used, although now it is hardly ever seen.

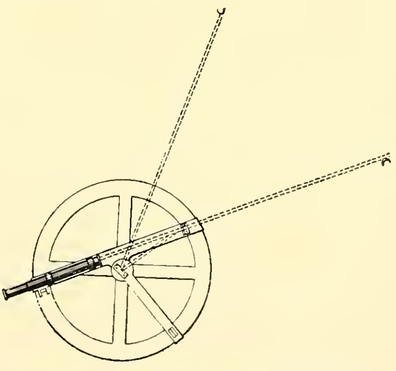


Fig. 24.—Borda's Reflecting Circle.

A form of Repeating Circle by Borda (Fig. 25), with two telescopes instead of mirrors, was the instrument with which the French measured their principal triangulation when Ramsden's theodolite was used in England for connecting the triangulation of England with France, and

it continued in use on the continent for a long time afterwards. However true it may be in principle that errors would be eliminated by repeating the angle round the circle, owing to structural difficulties, the instrument has not proved altogether successful, and at length has been almost entirely superseded for observations on land by the theodolite.

In order to improve the sextant, and to increase the angle which it is possible to measure, a prism was introduced

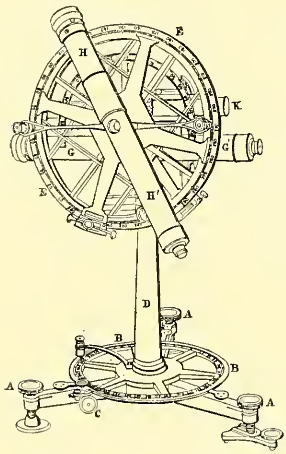


Fig. 25.—Repeating Circle.

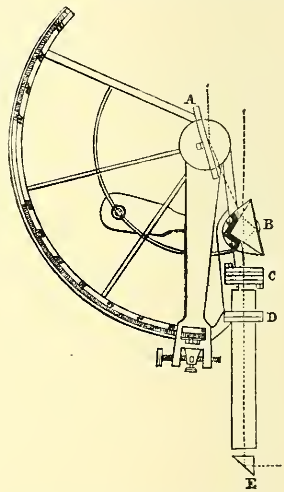


Fig. 26.—Prismatic Sextant.

by Pestor and Martins, of Berlin, as shown in Fig. 26. Others, without knowing of this invention, have suggested the same thing, and only quite recently it was proposed to me by a man, who considered it an entirely new idea.

I have dealt at considerable length with these instruments for observing at sea, as perhaps they have done more in the past towards map and chart making than any others. The coasts of the world have been charted chiefly by their use, and no small part have they taken in land exploration in the early days of pioneering expeditions. One of the

most revered relics in this Society's collection is the sextant used by Dr. Livingstone during his marvellous explorations in Central Africa.

The use of the sextant in preference to the theodolite in early exploration was due to a great extent to its portability, and in experienced hands quite good astronomical determinations can, of course, be made with it. But for horizontal angles in survey work it cannot compare with the theodolite, for unless the points are absolutely on the same horizontal line the angles measured may be considerably in error.

Naturally it is, as a rule, impossible to see the horizon

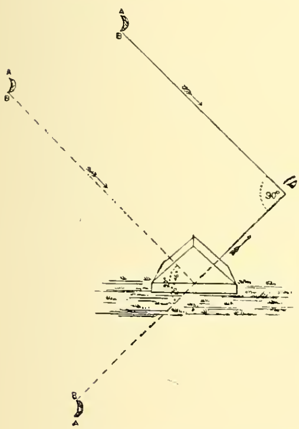


Fig. 27.—Principle of Artificial Horizon.

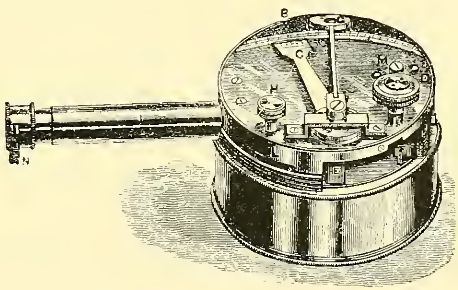


Fig. 28.—Pocket Sextant.

line on land, and so an *Artificial Horizon* has to be used, and then the angle measured with a sextant between the sun itself and its reflected image in the artificial horizon, divided by two, is the altitude. The artificial horizon is merely a reflecting surface, truly horizontal, and its principle will be clear from an inspection of Fig. 27. Attempts have been made from time to time to produce a small and portable form of sextant, and the well-known pocket sextant (Fig. 28) is the best known of these.

It may not be out of place here to trace briefly the principal devices proposed at different times for the accurate reading of angles on arcs of quadrants, sextants, and theodolites, the necessity for which was felt even in very early days. The first idea seems to have been only to increase the radius of the arc, and quadrants and sextants were constructed with arcs of surprisingly large dimensions, especially by the Arabs, of whom it is stated that they had such large arcs that it was possible to read directly to six seconds. Fig. 29, which is taken from Bleau's General Atlas, published at Amsterdam in 1664, shows one of these large quadrants. Of course these were fixed instruments for use in observatories, and not for travellers, although Picard, the noted French geodecist, in 1670, managed to carry about with him a quadrant of ten feet radius during his geodetic work in France in that year. The modern geographical surveyor often grumbles now at the weight and size of a theodolite with circles of only 5 or 6 inches in diameter, but what would he say to carrying about an instrument of this kind? Picard's idea was, of course, to give greater accuracy to the readings, but difficulties arose with this unwieldy instrument which do not seem to have been anticipated at first, amongst the most serious being the flexibility of the material of which the quadrant was constructed, which alone made it impossible to obtain reliable results. The stand

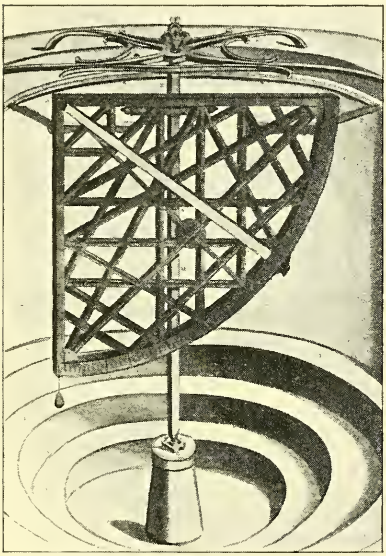


Fig. 29.—Old Quadrant.

was made of iron, and the limb bearing the quadrant was covered with copper. It is interesting to note that we have here at this date the first introduction of the telescope, with spider lines in the diaphragm, attached to angular measuring instruments, for although it was invented over sixty years before this date, Picard seems to have been the first to make practical use of it for this purpose. The reading of many of the large quadrants of an early date was facilitated by an ingenious diagonal scale arrangement, such as you see on the instrument in Fig. 30, and which must have been of considerable assistance in determining the small divisions. However, even with this, things were very unsatisfactory, and inventive minds were strenuously endeavouring to devise some more accurate method of reading the angles. About the middle of the sixteenth century, Peter Nunez, or Nonius in its Latin form, a Portuguese who had made considerable advance in the study of mathematics, devised an arrangement for giving

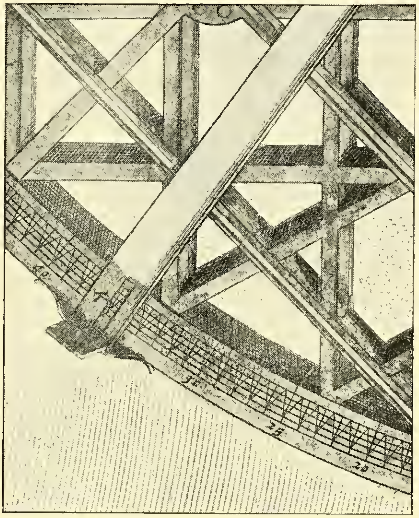


Fig. 30.—Diagonal Scale for increasing accuracy of reading Angles.

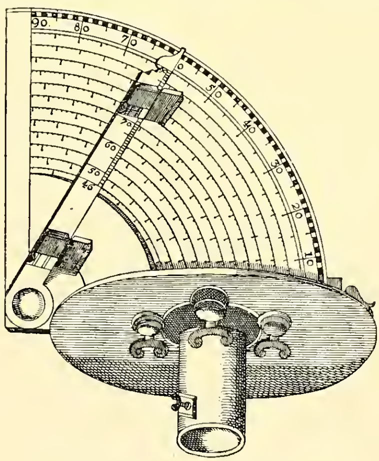


Fig. 31.—Quadrant with Nonius. (*From Dudley's 'Arcano del Mare.'*)

greater accuracy for readings, which afterwards bore his name, and was called the *Nonius* (Fig. 31). This consisted of a large series of concentric segments of circles, each divided into a different number of equal parts, the outer being graduated to 90, the others to 89, 88, 87, etc., divisions. As the fine edge of the pointer, which was directed at the sun or star, passed among these numerous divisions, it was practically certain to touch one of them—suppose the 15th division on the scale divided into 85 parts—then the angle was $\frac{15}{85}$ of 90°, equal to 15° 52′ 56″. Although ingenious, this arrangement was most cumbersome and unsatisfactory, and never came into great favour. It was for a long time confounded with the far more elegant and ingenious arrangement of the Frenchman, Francis Vernier, which is still the usual method of reading angles, but which wrongly, even now at times, is called the Nonius.

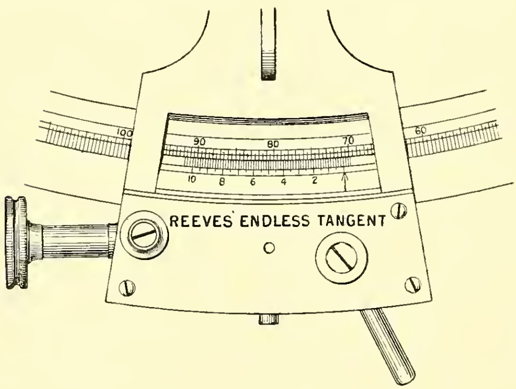


Fig. 32.—Vernier of Sextant.

In a letter addressed to Tycho Brahe, in 1590, by one Jacque Curtius, is perhaps to be found the suggestion of the *Vernier* (Fig. 32); but however that may be, Francis Vernier was the first to work out this most ingenious and simple arrangement, and bring it into practical use, which he did in 1630. The principle of the Vernier is so well known that it is not necessary for me to describe it here, but I will merely state that it consists of dividing a small separate and movable section of the arc upon which any

number of degrees of the principal arc has been marked off, into a slightly different number of divisions to that occupied by the same space in the arc itself; then, by noticing where the line on the arc coincides with a line on the small arc, or vernier, the reading can be at once obtained. Here, then, we have at last arrived at a more satisfactory method of reading angles, and one which has continued in general use for about 270 years, although the best theodolites for some

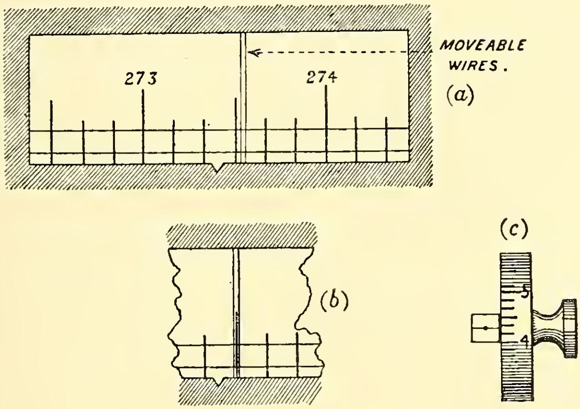


FIG. 33.—Reading Micrometer for Theodolite.
(*From 'Text Book of Topographical and Geographical Surveying.'*)

time past now have been fitted with a micrometer microscope for reading.

This micrometer arrangement, which was apparently first suggested by a young astronomer named Gascoigne (who fell at Marston Moor), in 1640, did not come into general use until long after, and, in fact, although Ramsden fitted his theodolites with micrometers, it is only in the last fifty years or so that it has become at all usual to fit them on to 5-inch or 6-inch theodolites, such as geographical surveyors generally use at the present time. The reading micrometer (Fig. 33) consists of a microscope in the diaphragm, to which is fixed a pair of movable wires, so

arranged that they pass from one division on the arc to the next at one turn of the drum or head of the micrometer screw. This drum is divided into five or ten seconds, so that when the space on the arc is ten minutes, it is possible to read by the micrometer to one or two seconds. The drawback to ordinary micrometer arrangements for travellers in rough countries is that they make the instruments bulky, and render it necessary to be carried in two cases instead of one; besides, they require most careful handling, or they

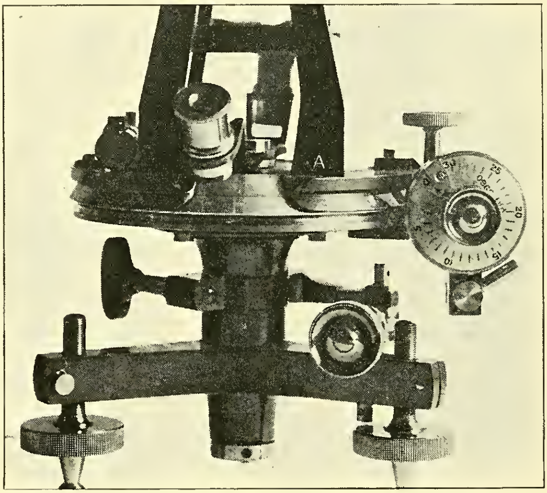


FIG. 34.—Reeves' Tangent Micrometer.

soon get out of adjustment. A new form of micrometer, certainly more compact and suitable for travellers who have to consider weight and bulk, is the Tangent Micrometer (Fig. 34). This I designed a few years ago, and it is now doing good work. A small 4-inch transit theodolite fitted with a pair of these is capable of giving readings to two or three seconds, with care.

As already stated, the Diopter of the ancient Greeks seems to have contained the first suggestion of the theodolite,

but how far there was any sort of resemblance it is impossible to say now. If we imagine the diopter fitted with circles there would certainly be a great deal in common between the two instruments; but there seems to be nothing to warrant any such conclusion. The true originator of the *theodolite* seems to have been Leonard Digges, of London,

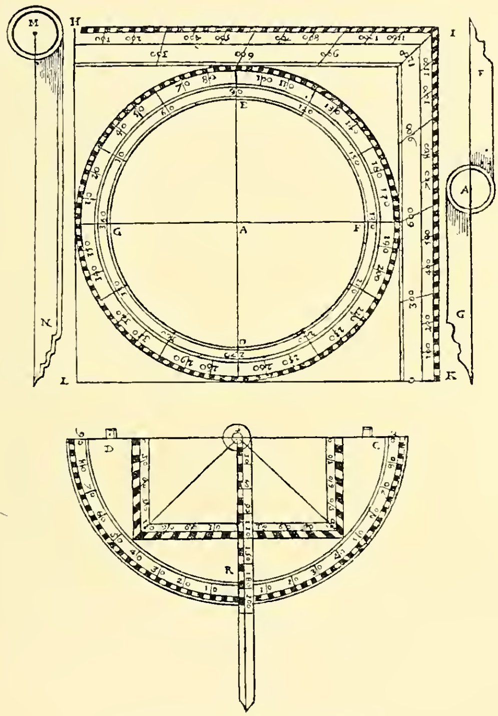


Fig. 35.—Digges' Theodolite.

whose invention is described in his book on surveying. This work was completed by his son, Thomas Digges, and published in 1571. Digges constructed his theodolite therefore a few years before this date. The name "theodolite," of which the origin is uncertain, although perhaps nothing more than a corruption of "the alidade," was first given by Digges. The theodolite of Digges (Fig. 35) was very

different from the modern instrument that goes by that name. There was, of course, no telescope and no vernier, and only a plumb-line for a level, so that it would be impossible to do accurate work with it; still, the principle of the modern instrument was there. A very interesting example of an early theodolite, much like that of Digges, is to be found in the Dutch atlas of Bleau (Fig. 36). This is especially interesting, as it shows that no

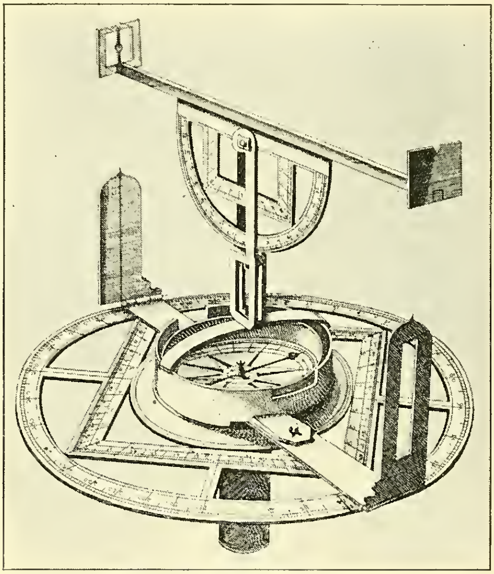


Fig. 36.—Old Theodolite.

great change seems to have been made in the design of the instrument for about eighty years. Here, Fig. 37, is an interesting old sketch, taken from Digges' book, showing his theodolite in use for finding the distance of a ship.

It is an interesting fact that the theodolite, doubtless the most important instrument for all exact survey work, was throughout an essentially English invention. I think

we may be proud of this. If Digges was the first to lead the way with his invention of about 1571, other Englishmen

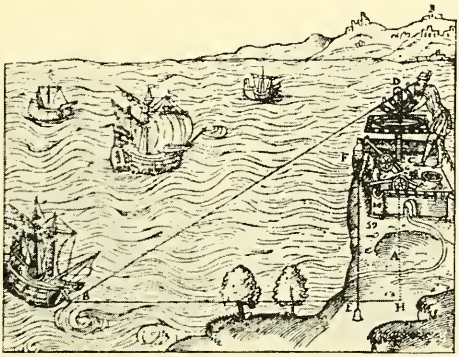


FIG. 37.—Digges' Theodolite in use.

gradually improved upon his idea; but it was not until the latter part of the eighteenth century that this instrument could really be called an accurate instrument for geodetic work. It was then that Ramsden, the ingenious instrument maker, constructed his famous theodolite (Fig. 38), which was first used on the triangulation of England in 1787, when it was decided between England and France to connect the triangulation of both countries. In 1763 Ramsden had invented a graduating machine for dividing the circles, and soon after commenced the construction of his well-known excellent theodolite, which after being used on the triangulation of this country for many years, and having done good service

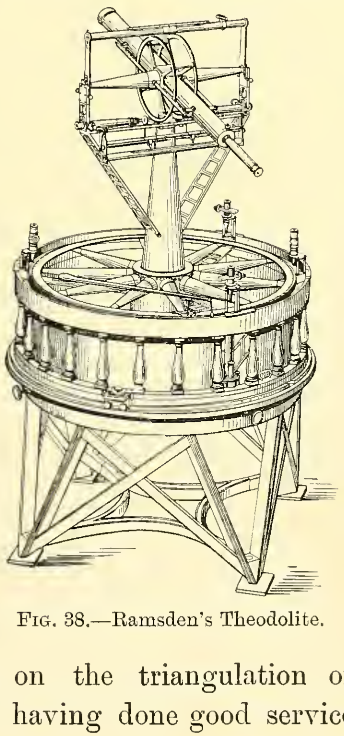


FIG. 38.—Ramsden's Theodolite.

in India, has now been placed on the retired list, and given a permanent home at the Ordnance Survey Office. Doubtless many of you have lately had an opportunity of inspecting this famous old instrument at the Franco-British Exhibition, where it stood in a glass case in a corner of the British Science section. It was constructed with a horizontal circle of three feet diameter, divided into fifteen-minute spaces which by the micrometers, originally three in number, can

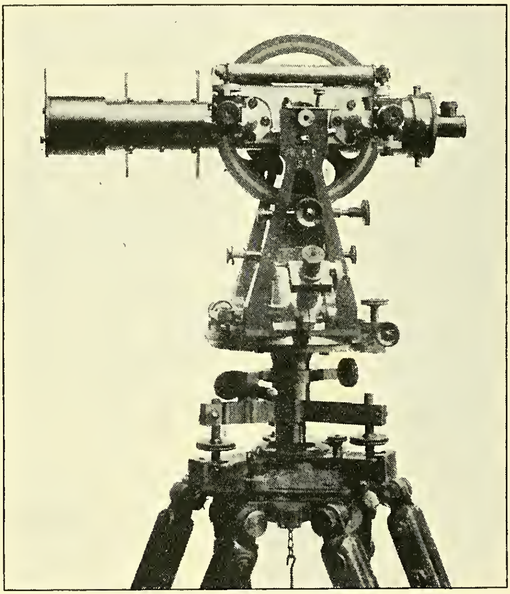


Fig. 39.—5-inch Transit Theodolite.

be read to single seconds. The vertical axis is about two feet above the circle. The telescope has a focal length of thirty-six inches, and a transverse axis of two feet in length, terminated by cylindrical pivots, about which, when supported above the axis of the theodolite, it is free to move in a vertical plane. A second instrument, almost identical with the first one, was shortly afterwards constructed. The great success of Ramsden's instrument, and its superiority over all

other angular measuring instruments, including the repeating circle, which still continued in use on the continent, served to give the theodolite the first place as a surveying instrument, at any rate in this country and in India; and the instrument used to-day is pretty much as Ramsden left it. There have been, of course, many secondary alterations, and Figs. 39, 40, 41, are photographs of some of the latest theodolites used in geographical surveying.

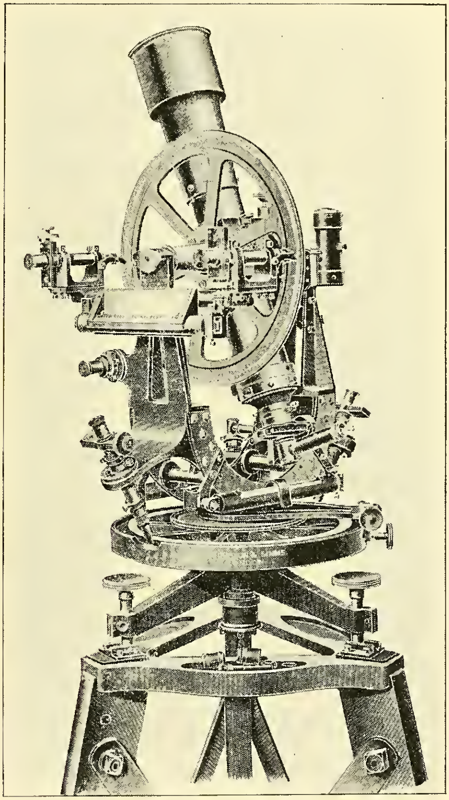


Fig. 40.—Transit Theodolite used on Indian Survey.

In Fergusson's Percentage Theodolite the circles are divided into octants, and instead of marking degrees, minutes and seconds in the usual manner, show at a glance the percentage of the right angle direction line indicated by the telescope to the initial direction. This percentage division is effected on the principle of the tangent of 45° being equal to radius. Each of the eight tangents is divided into 100 equal spaces, and lines are drawn from these spaces through the octant arc to the centre of the circle, making each of the 100 octant divisions subtended exactly $\frac{1}{100}$ of this tangent, and $\frac{1}{100}$ of the radius. In addition to these specially divided circles,

this theodolite is fitted with the ordinary ones, for reading the arc in the usual manner.

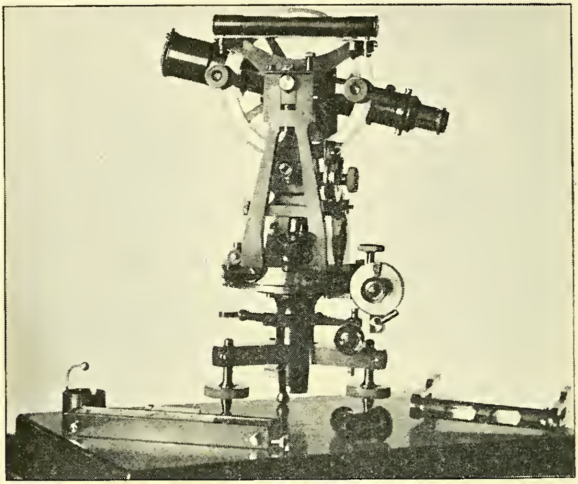


FIG. 41.—4-inch Transit Theodolite, with Tangent Micrometer.

Although it is impossible in this short lecture to give anything like a complete account of the history of the *Magnetic Compass*, yet this has played such an important part in geographical discovery and exploration, both by sea and land, that it must always be held in great reverence and esteem by geographers. According to Padre Bertelli, the magnetic needle was known to a few Chinese and Japanese from the Christian era, being used occasionally in navigation and for Emperors' journeys, and known as the "Indicator of the South." Whether introduced or invented by them, it is certain that a rough floating compass was in use in the Mediterranean about the tenth century A.D. by citizens of Amalfi. No mention of the compass needle is to be found in Greek or Latin works. The compass card, that is a needle carrying a card, was not made until the end of the thirteenth century. Some persons

do not agree with the idea that the compass came from China, and incline to the belief that it was invented by the Amalfians, and not introduced by them. Interesting notes by Prof. Giles, of Cambridge, on this subject have recently appeared in *Adversaria Sinica*, Nos. 4 and 7, and from these it seems possible that this "Indicator of the South," or "South Pointing Chariot," had nothing to do with magnetism at all, but was merely a mechanical contrivance connected with the wheels of a chariot, so that a certain pointer arrangement was, by means of tooth wheels, made to indicate the southerly direction however much the chariot altered its course. Fig. 42 shows an old Chinese compass.

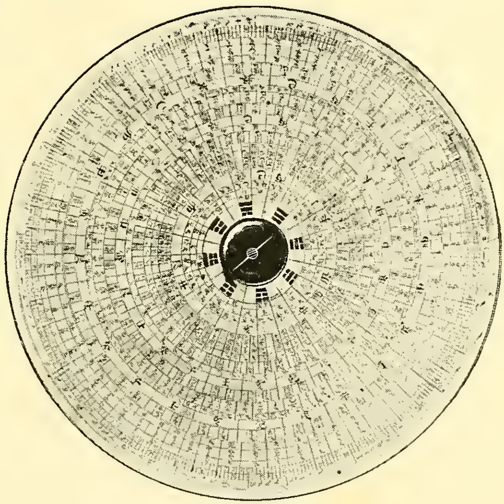


Fig. 42.—Chinese Compass.
(*From R.G.S. Collection.*)

Immediately after the compass became known in Europe in the tenth century, its influence began to make itself felt on navigation, and the mariner, instead of following round the coast-line, fearing to venture out into the unknown, became bolder, left the old beaten tracks, and struck out new routes across seas and oceans which before he would never dare to attempt. But for the compass we should in all probability never have had such voyages as that of Columbus, Vasco da Gama, and Magellan, for although there were venturesome spirits in those days, there were probably few who had sufficient knowledge of astronomy to trust to the stars for their guidance

over long voyages away from land. Probably that mysterious question of variation of the compass did not worry the early navigators of the Mediterranean, and there it would at any rate in those days not have been more than a small amount. But when they began to leave their old haunts and to venture into the Atlantic, naturally it would become a serious matter, and we all know how perplexing a question this was to Columbus on his great voyage. Here are two views (Figs. 43 and 44) of old ship's compasses which will give a good idea of the sort of thing the famous navigators of the fifteenth and sixteenth centuries had to steer by.

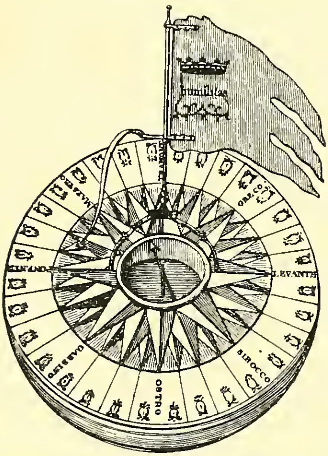


FIG. 43.—15th Century Compass.
(*From Laussedet's 'Recherches sur les Instruments,' etc.*)

One great advantage the sailor had in those days, was that he had no occasion to worry his head about deviation due to iron in the construction of his ship.

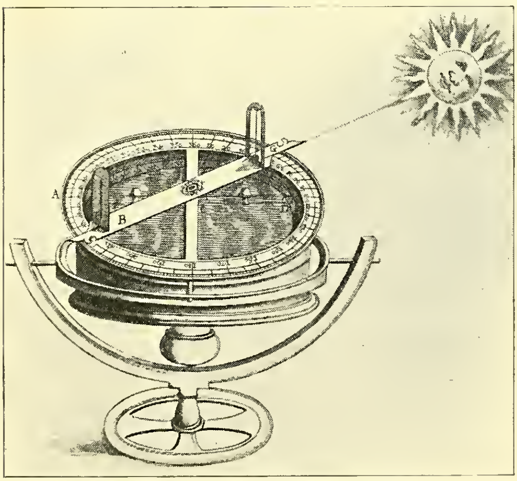


FIG. 44.—Old Ship's Compass.
(*From Dudley's 'Arcano del Mare.'*)

The marine compass remained pretty much the same for many years, and it was not until comparatively recent times that any great improvements were introduced in it. In 1813 Francis Crow, of Faversham, introduced liquid into

the bowl of the compass, for the first time, to steady the compass card. When iron ships were built, things were upset tremendously, and all sorts of contrivances were resorted to to correct for the deviation caused by the iron, and even now this is a most troublesome business.

It had been proved that a light magnetic needle with a maximum amount of surface and a minimum amount of weight, was more sensitive, and generally more accurate, than a heavy one with a small amount of surface, and the late Lord Kelvin, to whom navigation owes so much, constructed a standard compass on this principle, and arranged a series of light needles, parallel with one another, instead of one single needle. This was a great improvement, and in addition to other advantages reduced frictional error to a minimum.

If some really good and reliable compass, working on another principle altogether, and entirely independent of magnetism, could be invented, it would supply a long-felt want, specially as there would be no trouble then about "variation" or "deviation." Several attempts have been made in recent years to produce such a compass, which have generally, though not invariably, been based upon the principle of the gyroscope combined with the rotation of the earth. The latest and apparently most successful compass of this kind is the gyrocompass of Dr. Anschütz-Kaempfe, which made its appearance last year, and a full description of this interesting instrument is to be found in the transactions of the Schiftbautechnische Gesellschaft zu Berlin for 1909. It is early yet to say how far this compass will be practically successful, but from experiments made it promises to do well.

It is not only with the marine compass of the navigator that geographers are interested, much as they owe to it for the charting of unknown coast-lines and

islands, but the smaller form of the instrument, such as used on river navigation and on travels on land, has perhaps done more than any other instrument to fill up the blank

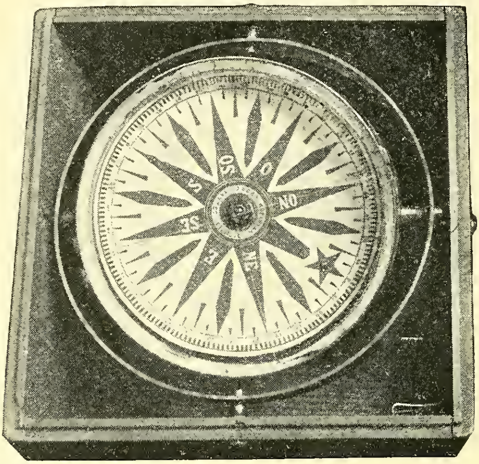


FIG. 45.—Livingstone's Boat Compass.
(*From R.G.S. Collection.*)

places on our maps. A most venerable and highly interesting instrument of the boat compass class, is shown in Fig. 45, which is the original compass used by Dr. Livingstone on his memorable journey down the Zambezi in 1855, and by which he, for the first time, explored and constructed a chart of this river as far as to the Indian Ocean.

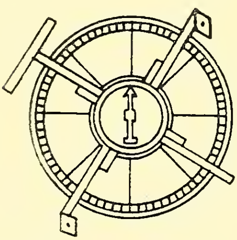


FIG. 46.—Old Surveying Compass.
(*From Laussedet's 'Recherches sur les Instruments,' etc.*)

The date when the compass was first used for land surveying is not known exactly, but it was probably about the early part of the sixteenth century. Fig. 46 represents the compass of Nicolo Tartaglia, from his book written in Venice between 1520 and 1560. There are one or two interesting points about this old compass, especially the sighting alidade.

The graphometre of Danfrie had also a compass in the centre, which would give the magnetic bearing of any point on the survey made with this instrument. I must not go further into the development of the compass here, but will merely show (Figs. 47, 48) two of the latest forms of prismatic compasses for travellers. Fig. 48 is specially fitted for marching, and the bearings are rendered visible at night by luminous paint.

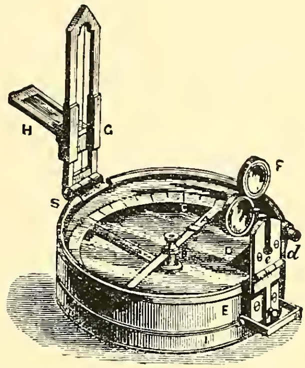


FIG. 47.—Prismatic Compass.

In concluding this section I would venture to call attention to the new *Astronomical Compass and Time Indicator* (Figs. 49 and 50). This is a simple and inexpensive little instrument for quickly finding the north and south line and the true bearing of any object, as well as local mean time, by the sun and stars, with sufficient accuracy for ordinary purposes. It has been designed by me for use in marching when the magnetic compass cannot be relied on, and to find the variation of the compass and serve as a check on bearings taken with a prismatic, as well as for quickly finding approximate time when no other means are available. A description of it appeared in the *Geographical Journal* for December, 1908.

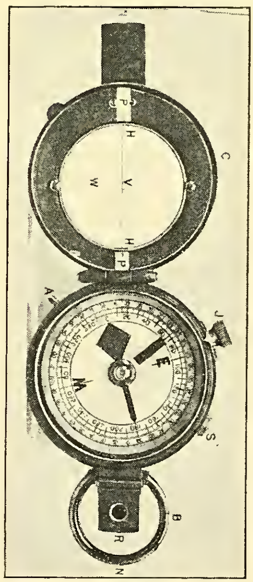


FIG. 48.—Prismatic Compass (Military Pattern).

No attempt will be made to give a history of the invention and construction of timekeepers, for *chronometers*, although indispensable

in fixing positions in longitude, are not confined to this use, and I can only give a few brief notes concerning the

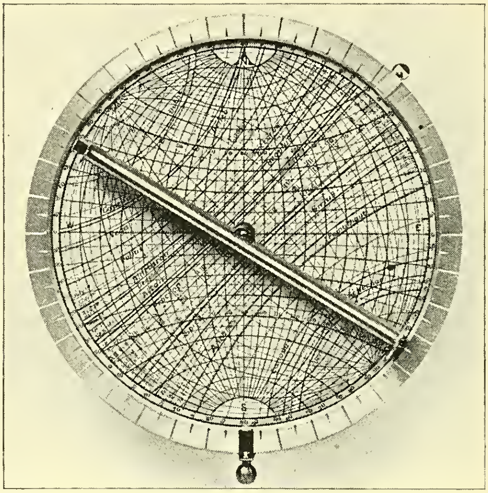


FIG. 49.—Reeves' Astronomical Compass (Front).

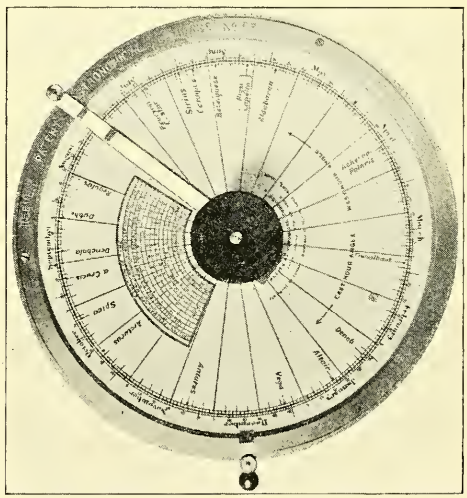


FIG. 50.—Reeves' Astronomical Compass (Back).

method of determining time. The earliest method of all seems to have been by the length of the shadow of the sun

cast by an upright stick or rod, which, of course, varies with the day, being naturally shortest at midday when the sun is on the meridian. Later, this was improved by placing the Gnomon, or rod, parallel with the axis of the earth, which means elevating it to the angle equal to the latitude of the place; and again by fixing it in the bowl, known as the Scaph, as previously described. Another method of measuring short intervals of time adopted in early years, was that of noting the quantity of water which passed through a small orifice in a vessel.

Much the same sort of thing was the device of the hour-glass, in which a certain quantity of fine sand was allowed to pass from one part of a vessel to another through a fine hole; and it is remarkable that although these were the most primitive form of time measurers, so old in fact that the exact date is lost in antiquity, yet both the sundial and hour-glass have never really died out entirely, and are still with us in spite of the great improvements in time measurers.

King Alfred is said to have used candles for measurement of time, by knowing how much burnt in certain intervals. However, we cannot stay to discuss these most primitive ways further, but must pass on to the more accurate methods and means of measuring time.

Like nearly all excellent things in common use, the chronometer is the outcome of many centuries of improvement, and has gradually been evolved from the earliest and crudest forms of machine. The exact date of the construction of the first clock is unknown, but it appears that the monk Gerbert, afterwards Pope Sylvester II., constructed a machine for marking intervals of time at Magdeburg as early as A.D. 996. This had a weight for motive power. Weight clocks seem to have been in pretty general use in the monasteries of Europe in the eleventh

century, although they were probably without dials and hands, and consisted merely of an arrangement for striking a bell at certain intervals as a call to prayers. Portable clocks came into use in the fourteenth century. These were doubtless actuated by a mainspring instead of by weight, and the Society of Antiquaries has one of these early portable clocks made by Jacob Zech, at Prague, in 1525. In addition to the spring there is a fusee, by which arrangement the pressure of the spring is equalized. The pendulum, as a regulating power of the clock, was a most important invention, due, as is generally accepted, to Huygens, the learned Dutch scientist. Considerable discussion has at times taken place as to this, but, at any rate, Huygens was the first to bring the pendulum clock into practical use, which he did in 1657. Dr. Hook brought an improved form of pendulum before the Royal Society in 1666, and this was introduced in clocks in 1680. The so-called "Nuremberg-Eggs" were manufactured by Peter Hale of Nuremberg about 1490. They were of oval shape, hence their name. Watches were in use in England as early as Henry VIII.'s time, yet they did not become at all general until the reign of Queen Elizabeth, and then their cost was so great that only the wealthy could afford to have them.

The chronometer used for astronomical determination of time and longitude is nothing more or less than a very accurately constructed watch, although, of course, larger than an ordinary watch. Special care has to be taken with the compensation of the balance, so that its rate may not be affected by change of temperature. To prevent this alteration of rate due to the unequal contraction and expansion, an arrangement for compensation was first introduced by John Harrison in 1735, who placed in the balance a bar of brass and steel, so arranged that as it contracted and

expanded by changes of temperature, it regulated the affective length of the balance spring to which it was attached, and thus equalized the rate. An improved system of compensation was introduced in 1782 by John Arnold, modified afterwards by Thomas Earnshaw, and this is the system now generally employed. The history of Harrison's chronometer is interesting. In 1713 the Government offered prizes of £10,000, £15,000, and £20,000, to any one who could discover a method of determining longitude at sea within 60, 40, and 30 miles respectively, and John Harrison, a native of Wragby, Yorkshire, who in his early days showed that he possessed a great talent for mechanics, and had helped his father in repairing clocks, made up his mind to win one of these prizes. In 1728 he came to London with drawings of his chronometer, including his arrangement for compensation, but was advised to construct one before submitting his plans to the authorities. At last, in 1735, he had a chronometer finished, and obtained certificates of excellence from Halley, the Astronomer Royal, and others, and it was put to a thorough test by sending Harrison with it to Lisbon. During this voyage so good was the performance that the longitude of several places was corrected, and six days after his return, the Board of Longitude awarded him £500 in two parts. Harrison completed a second chronometer in 1739, and two others afterwards. The fourth was of pocket form, and performed so well, that after a trial voyage from Portsmouth to Jamaica and back, lasting from November 18, 1761, to March 26, 1762, it was found to be only 1 min. 54·5 secs. in error. Still he had great difficulty in getting the prize out of the Government; and it was only after finally constructing a fifth chronometer, which went for ten weeks with only varying 4·5 secs., that he obtained the well-earned reward, and then entirely through the King

interfering directly on his behalf. Captain Cook carried a pocket chronometer made on Harrison's principle in all his famous voyages round the world, and four of Harrison's chronometers are now preserved in the Royal Observatory, Greenwich. The chronometer used by Captain Cook during his voyage of discovery in 1772–75, is now in the museum of the Royal United Service Institution.

In recent years a metal called *Invar*, an alloy of nickle

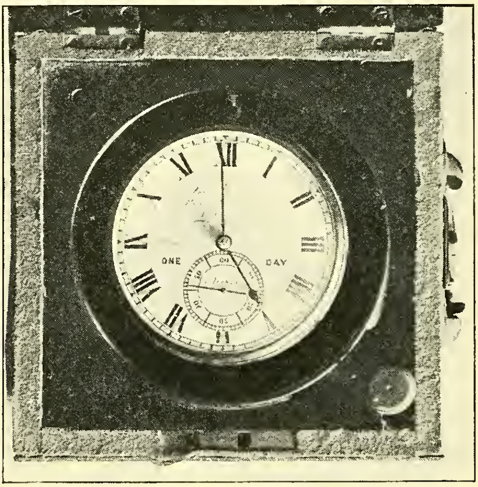


FIG. 51.—Captain J. Parry's Chronometer.
(*From R.G.S. Collection.*)

and steel, has been introduced, in which the coefficient of expansion is so small that it is practically negligible, and this metal is now being used in the construction of chronometer balances, so that it is to be hoped that the compensation difficulty will soon be simply and efficiently overcome; although I learn that at present there are certain practical difficulties in the way.

The accurate determination of time is such an important matter in finding longitude that a considerable amount of labour and skill has for years been devoted to devising the best means at constructing chronometers, and although

perfection is not yet obtained, the rates at times are surprising. The Royal Geographical Society has in its collection an interesting chronometer (Fig. 51), which has a remarkable history. It was used by Captain J. Parry on board H.M.S. *Hecla*, on his voyage for the discovery of the North-West Passage in 1828, and subsequently by H.M.S. *Volage* during her voyage round the world in 1826–29. Previous to being taken over by Captain Parry, the chronometer had in the same year gained the first prize at Greenwich, its variation for a period of twelve months being only 1·11 secs.

For the purpose of rough land travel, the ship's chronometer, although it has frequently been carried, is not altogether satisfactory. The large and heavy balance is liable to be disturbed by jolts and shocks, and very often stops altogether. Therefore, for more than twenty-five years past, travellers have been recommended by this Society to take for their observations on land, one of the so-called half-chronometer watches, which is shown in Fig. 52. This is really a most carefully constructed and compensated lever watch, in a water-tight case, designed by my predecessor, Mr. J. Coles.

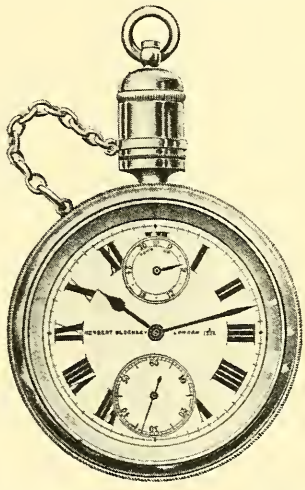


Fig. 52.—Half-chronometer Watch in Water-tight Case.

So far, with the exception of the chronometer, we have dealt only with instruments for measuring and reading angles, from which position of places could be computed by trigonometry. But there is another class of instrument used by surveyors, and this includes those by which a graphic representation of the country is obtained at once in the

field, without the necessity of computation. In this class may be included the plane-table, and the various photographic methods. I will now deal with the *plane-table,* and endeavour to give you a rapid account of its development. In principle, the plane-table is simplicity itself, and consists of a drawing-board on a tripod-stand, used in conjunction with a sighting-ruler or alidade. A base-line is measured on the ground to be mapped. At each end of the base-line rays are drawn on the board to the points in nature which it is desired to lay down on the map, and the intersection of the rays drawn from different ends of the base, to the same object, by the principle of similar angles and figures, fixes the position of this particular point on the plane-table board.

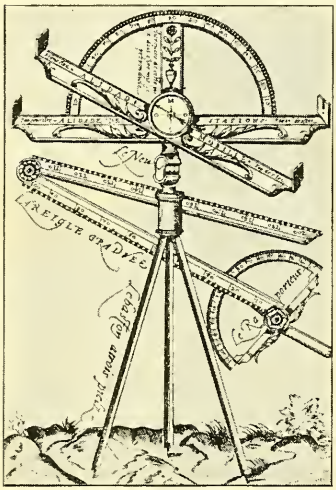


Fig. 53.—Graphometre.
(*From Laussedet's 'Recherches sur les Instruments,' etc*)

The idea of the graphic representation of angles is of very ancient date, and probably goes back to the days of the early Greeks. With their knowledge of geometry, it is more than likely that these wonderful old philosophers found ready means of constructing plans on some such principle. However, it was not until the sixteenth century that we have any very definite information about this method of surveying. In the year 1597 Phillip Danfrie, of Paris, invented and described an ingenious instrument called the *Graphometre,* by which angles could be measured and drawn on the plan without the necessity of computation. The instrument (Fig. 53) could be arranged either in a vertical or horizontal position, the former for finding heights, and the latter was used for horizontal plans. It

consisted of two alidades, one fixed, and the other movable; while attached to the centre of the fixed alidade was a large protractor. When used for making a plan, the surveyor would stand at one end of a measured base-line, and with the fixed alidade sight the other end; then, clamping the instrument in this position, he would move the other alidade on the point he desired to fix. This would be repeated at the other end of the base, and the intersection of the two rays would, of course, give the position of the point on the plan. It would not be necessary to read the

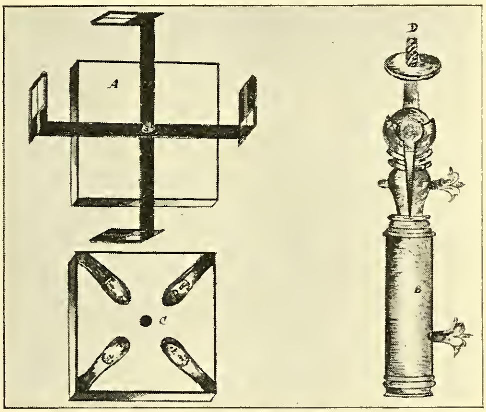


FIG. 54.—The Infallible.

angles, although this could be done if desired, as they could be drawn at once on to paper, and so the plan could be graphically constructed, as we do now on the plane-table.

Phillip Danfrie also brought out another instrument—a sort of modification of the graphometre—which he called the *Trigonometre:* it was really a sort of range-finder, and consisted of three movable arms. Sighting along the base-line at one station, one of the arms would be set on to a distant point, and then, taking the instrument to the other end of the base, the other arm would be set on to the same

point. The intersection of the two arms then gave the distance, which could be read off the scales engraved on the arms.

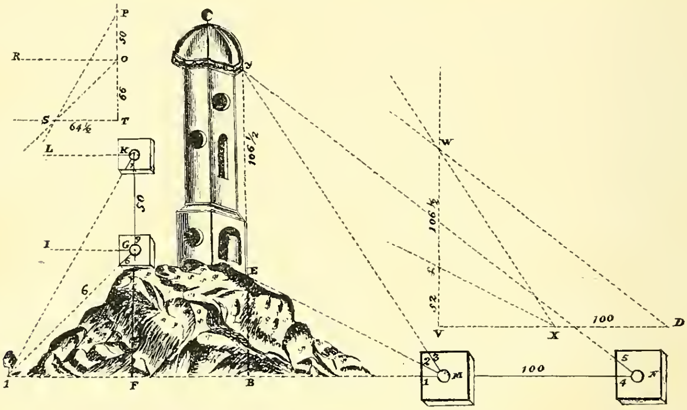


FIG. 55.—Infallible used vertically.

In an old manuscript book on surveying, in my possession, by J. Douglas, dated 1724, is described an early form of plane-table, which the author calls the *Infallible* (Fig. 54). There are, in this book, some striking drawings of examples of using this instrument, one of which (Fig. 55) is of decided interest. It shows the instrument used vertically for finding the height of a tower.

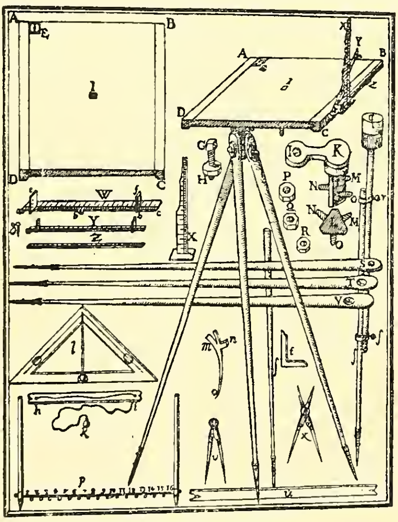


FIG. 56.—Prætorius' Plane-table.
(*From Laussedet's 'Recherches sur les Instruments,' etc.*)

About the year 1590, the German, Jean Prætorius, who was for some years Professor of Mathematics at Wittenberg, and a very clever mechanic, invented a plane-table which, in general design and completeness of detail, would compare very

favourably with many modern instruments. It is shown in Fig. 56, and is certainly a most creditable production.

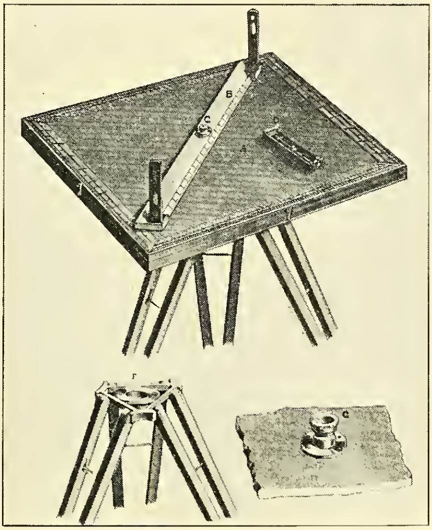


Fig. 57.—Plane-table.

Although large water-levels were of a very early date, so far, the small and compact spirit-level had not made its

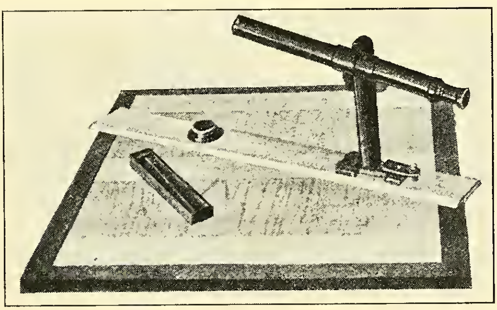


Fig. 58.—Plane-table with Reeves' Folding Telescopic Alidade.

appearance, and strange to say did not come into existence until nearly a century later, when it was invented by

Melchisedech Thevenot, so that in this plane-table of Prætorius, the level is merely a plumb-bob on a triangle.

Figs. 57, 58, and 59 show three of the latest pattern plane-tables, the last of which, Fig. 59, is a photograph of my *Distance Finder Alidade* used in conjunction with a

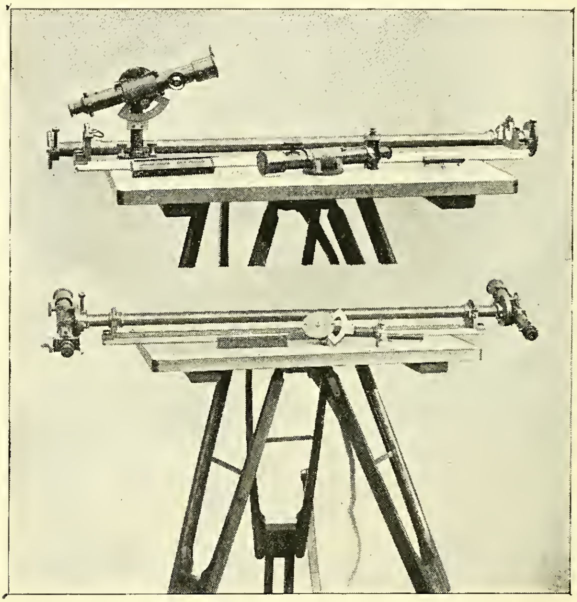


Fig. 59.—Plane-table with Reeves' Distance Finder Alidade.

plane-table. This, while serving as an excellent telescopic alidade of the usual type, can be so arranged by fixing a telescope at each end, that distances can be found directly without any computation.

In America and on the Continent most elaborate plane-tables are constructed, with telescopes, vertical circles, levelling-screws, and many other elaborations—in fact, they approach, in many respects, a theodolite. In this country and in India we make no attempt to combine plane-tables with theodolites, but construct them in the simplest possible

manner. If a telescope alidade is used, it is for the sake of clearing definition of distant points, and the small circle only serves to give rough differences of altitude. Whilst the theodolite is essentially an English instrument from its first inception to the latest development, the plane-table has until comparatively recent years received but scanty attention in this country. For some reason or other, it has not been used as much as it might have been by us, and until the Indian surveyors showed what excellent detailed topographical work could be done with it, it was really little appreciated here.

Belonging to an entirely different class from those we have so far considered, are those instruments which may be ranked under the general term *Tacheometers* (Greek ταχὺς, swift; and μέτρον, a measure). Although there are many different kinds and patterns, and as many different names borne by them, yet they all depend upon the same principle, *i.e.* of obtaining the distance by the accurate measurement of the small angle subtended by a rod or a short known distance. The angle being known and the length of the rod, it is of course a simple matter of trigonometry to find the distance—or it can be taken direct from a table. There are two great divisions of these instruments, and notwithstanding the many forms and apparent great differences, they may all be classed under one or the other of these divisions. The first consists of fixed wires in the diaphragm of a telescope, with a changing measure on the rod, and the other of a fixed rod with the varying space between the wires in the telescope. In the first, the wires, or fine cuts on the glass diaphragm, are generally spaced in the proportion of 1 to 100 of distance, so that at a distance of 100 feet, one foot is just included between the wires, two feet at 200 feet distance, the distance in fact being read off the rod direct. Fig. 60 illustrates the principle, but

supposes a plain tube to be used, such as was first employed. Here it is evident that $ab : \mathrm{AB} : : a\mathrm{C} : \mathrm{AC}$. When a telescope is used the matter becomes more complicated, for the factor hair distance varies with the focus, so that there is no longer a single ratio as a multiplier for determining the distance, and to simplify the computation the varying ratio is reduced to a single ratio, plus a constant. The constant equals the focal length of the telescope plus the distance of the object glass to the central rotation axis of the telescope, or say about 18 inches in an ordinary telescope. An arrangement can be made by adding another lense so that the correct distance can be obtained at once. This was first proposed by Porro, an Italian, in 1823, who brought out a telescope called the Anallatic Stadia telescope.

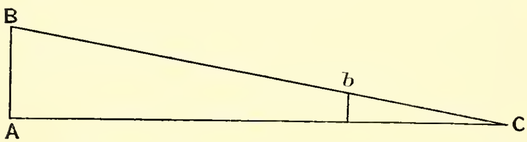


FIG. 60.—Principle of Tacheometer.

When distances are measured up or down slopes, and the rod is not held in a vertical position, corrections have to be made, either by computation or by tables. It is impossible in this short sketch even to mention all the kinds of tacheometers coming within this first division. There are many excellent works dealing with them, and to these I would recommend any one who wants further information.

In the second class the tacheometers, usually described as subtense instruments, differ from the first as stated in the fact that the rod is a fixed length, generally 10 or 20 feet, while the distance between the micrometer wires is variable. For long distances it may be considered that the focus is fixed; then as before, the angle being measurable with a micrometer, the distance can be readily found. This is the best form for long-distance work, as no figures have to be read off the

staff, the angle between the targets at the end of the rod being intercepted by the micrometer wires, and the distances computed, or taken from a table. A weak point in both of these classes is that they are useless for inaccessible points, such as across ravines, as a rod has to be sent on ahead in all cases. But with the Distance-Finder (Fig. 59) this difficulty is obviated. In all tacheometers, the accuracy may be taken as varying inversely as the square of the distance, but as a sort of general rule an error of about 1 : 300 may be expected for distances well within the range of the instrument.

The invention of the tacheometer and stadia measurement is an interesting subject. In a work published in London, 1778, Mr. William Green describes the method of stadia measurement by means of fixed wires, and it is to him that this important invention is generally, and to a certain extent justly, attributed. But, as in many such cases, others had been previously working in the same field, and as long ago as 1659 Huygens had constructed a micrometer eye-piece of a rudimentary sort; but it was improved considerably in 1662, when the Marquis de Malvasia made his *reseau* of silver wires. These were used for astronomical measurements by observing how many wires the diameter of a planet or a distance between two stars covered. Montanari, a little later, in 1674, seems to have been the first to suggest the measurement of terrestrial distances on this principle. In that year he replaced the silver wires by hairs, and applied the diaphragm to land surveying. In 1748, the celebrated astronomer, Tobias Mayer, constructed a micrometer eye-piece for astronomical measurements, by tracing fine lines on a thin disc of glass; and soon after, in 1764–73, Brander constructed the first glass diaphragms with fine lines cut on them, by means of a diamond's point, and applied them to the measurement of

distances. Specimens of his work can still be seen in the Royal Academy of Science at Munich.

It is a strange coincidence, and yet one that often occurs in such matters, that Brander and Green were both working about the same time at the same subject without knowing what the other was doing.

Such is a brief sketch of the early invention of this system of measuring distances, but naturally since that date

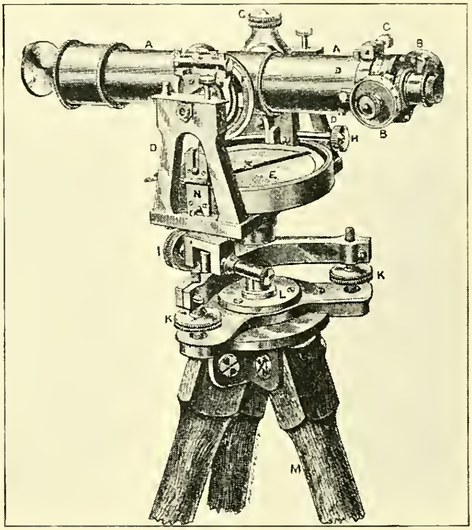


Fig. 61.—Subtense Instrument.

many improvements have been introduced. On the Survey of India it is usual to employ a fixed rod of 10 or 20 feet, and measure the angle subtended by this rod, by a double-position micrometer, as shown in Fig. 61. The late Colonel Tanner, of the Indian Survey, obtained good distances by means of an ordinary theodolite, by repeating the angle subtended by a rod on the horizontal circle, and then obtaining a good mean. Special kinds of distance finders and range finders, such as the Barr and Stroud, the Labbez, the

Topometer, and many others, might be mentioned, but in this brief review it is impossible to go into detail, and I must refer those interested to the works dealing with the various forms of tacheometers and range finders for further information.

Nothing has been said so far about the determination of heights by change in atmospheric pressure, but the instruments used for this purpose will be briefly referred to in the next lecture, when the various methods by which this is accomplished are described.

II

PRINCIPLES AND METHODS OF GEOGRAPHICAL SURVEYING, WITH A SHORT ACCOUNT OF THEIR DEVELOPMENT

In the last lecture we were occupied with a general review of the principal survey instruments, and traced briefly their development from the earliest forms to those with which we are familiar at the present day.

I now propose to deal with the second stage of our subject, and give you some idea of the principles and methods of geographical surveying, upon which all maps and charts depend, or, at any rate, are supposed to depend. It must be confessed that in times gone by the explorer was often allowed considerable licence, and where exact survey work was lacking a fertile imagination made up the deficiencies. Nor am I sure that this is altogether a thing of the past, for quite recently I heard of a certain individual whose name I have conveniently forgotten, who in a certain region which I will not mention was employed to do survey work, but who, instead of standing out in the cold with his plane-table, as most men would have done, was found to have filled the greater part of his plane-table sheet with topographical features evolved from his imagination while he was comfortably seated in a good warm tent. Still, we must take it that the usual thing is to construct the map from some sort of a survey, though it may be a very rough one, and it is chiefly with the methods of geographical surveying that we will now occupy ourselves for a short time, leaving the actual construction of the finished map till the next lecture.

As a foundation for all accurate surveying and map-making of any considerable part of the earth's surface, a knowledge of the true form and size of the earth is indispensable. So I propose to refer briefly to this part of the subject at the commencement of this lecture, and, as a start, will try to give you some idea of what the earth was considered to be like in early days.

According to Strabo, Anaximander, who was born in B.C. 612, was the first to construct a map of the world, but,

FIG. 62.

however this may be, little is known of this map, nor is it possible to say now what it was like. Anaximander's map was improved by Hecatæus, who lived in the same century; but as neither of these maps have survived to our day, it is only by our knowledge of the accepted geography of the times that we can tell at all what they were like. Fig. 62 shows what may be considered a reconstruction of Hecatæus's map of B.C. 500.

The earth, as understood by the Greeks at that time,

was generally supposed to be a flat oval plane or disc, broadest in the east and west direction, to which supposed fact the terms latitude and longitude, which have survived to the present time, owe their origin. Surrounding this disc-like earth was the Ocean or Great River, and in the centre of the plane was Greece itself. The furthest known point were the pillars of Hercules, or Straits of Gibraltar, on the West; the Black and Caspian Seas on the East; Africa, as far as the deserts, on the South, and the countries bordering the northern shores of the Mediterranean on the North. It was supposed that the sun passed under the earth plane in the evening to the west, and appeared again in the east the next morning. This idea of things sufficed for a time, and after all accorded with what a person on a lofty summit would observe. Strange as it may appear, flat-earth ideas, or perhaps better still, inverted-saucer earth theories, have even now their advocates, and the most remarkable maps of this kind are sent to our Society from time to time. They are interesting as curiosities, if for nothing else.

Who the bold old philosopher was who first declared the earth to be spherical is now never likely to be known with certainty; but the spherical form of the earth was probably accepted at a very early period by the Chaldæan and Egyptian astronomers, and, like much other knowledge, was introduced into Greece about the sixth century B.C. It was held by Pythagoras, who had travelled in the east, and his followers. Strabo, who lived in the first century of the present era, believed it, although he held the earth to be motionless, and had many other remarkable notions concerning it.

Many strange forms were given to the earth in early days. The Hindus believed it to be in the form of a boat or saucer upside down, resting on the heads of four elephants which stood on the back of an immense tortoise (Fig. 63). If

any one was inquisitive enough to ask what the tortoise rested upon he would be told that it was upon the universal ocean, but further than this the inquiry must not be pressed. Still, if some troublesome and persistent person should ask what the ocean rested upon, he would probably be told that it went all the way down to the bottom, or something of that kind.

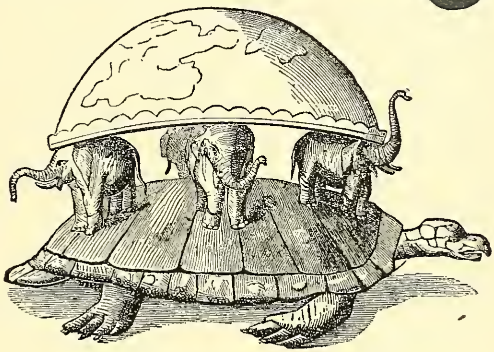


FIG. 63.—Hindu World.
(*From Gore's 'Geodesy.'*)

During the dark days of the Middle Ages, science and natural philosophy, like most other things, were lost in superstition and obscurity. The spherical idea of the earth was supposed to be not in accordance with Scripture, and all sorts of monstrous forms and shapes were substituted for it. Cosmas (surnamed Indicopleustes), A.D. 538, who had travelled as far as India, considered the earth to be something as you see it in Fig. 64.

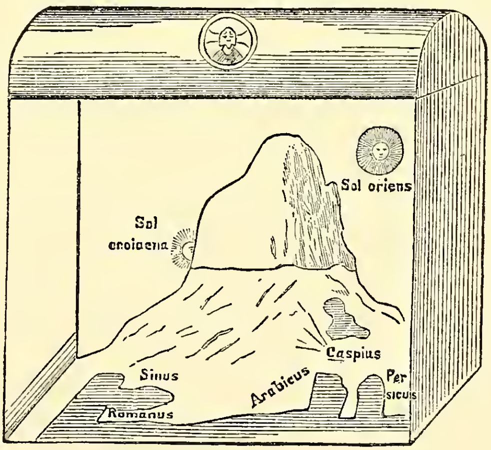


FIG. 64.—Cosmas' World, A.D. 538.
(*From Gore's 'Geodesy.'*)

The habitable regions were represented as a parallelogram surrounded by an ocean; on the four edges of the earth rise four walls which enclose it, while the top forms the

heavens. The sun was supposed to pass behind a high hill at night and come out again in the morning on the other side. Cosmas said that this must be the true form of the earth, as it resembled that of the Tabernacle in the wilderness, of which God gave Moses full details for construction, and doubtless the earth was built on the same

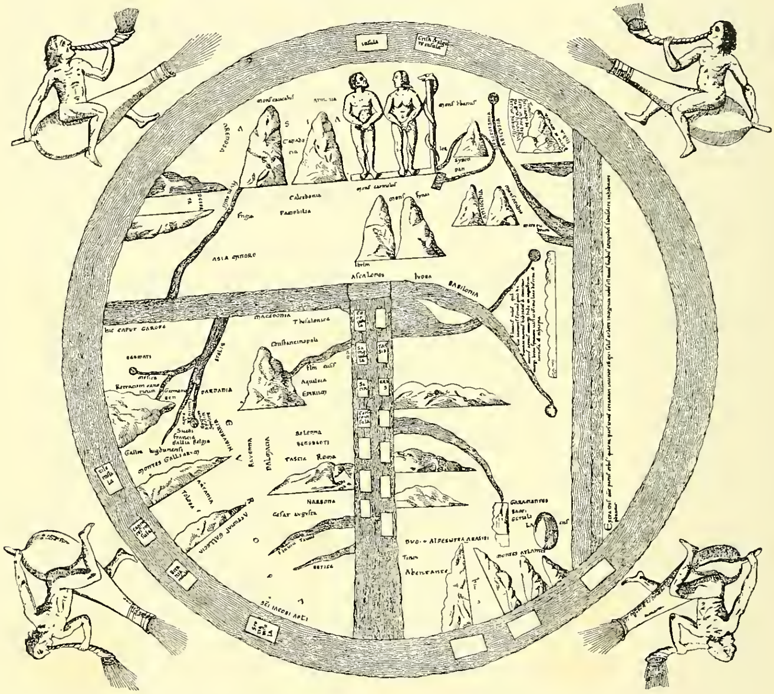


Fig. 65.—Map of World, 12th Century A.D.

lines; to us not a very obvious conclusion to arrive at. The Venerable Bede, who lived in the eighth century of our era, taught that the earth was in the shape of an egg, and later on many other weird world-maps were constructed, for the greater part, purely from fancy. I will now show (Fig. 65) a twelfth-century map from the manuscript in the library at Turin. In this, and others of the period, it was

considered the proper thing to place Jerusalem and Palestine in the centre of the world, like the hub of a wheel, while other nations were honoured with positions more or less remote. One can readily appreciate the reason for this, but truth had to give place to sentiment, as, alas! it has often done with the same disastrous results. This so-called "hub" theory was not confined to Middle-Age Christian maps: the Greeks made Olympus the centre; the Assyrians, Babylon; whilst the Chinese have always regarded their land as the central empire of the world, assigning to the surrounding countries the outlying fragments of the earth, as they thought fit.

We must go back now to the times of the early Greek philosophers, for as we leave them, for many years, as we have seen, the darkness only thickens in all scientific matters.

It was only natural that, having once come to the conclusion that the earth was spherical, the question of its dimensions should present itself for solution. But how was this to be accomplished? It is difficult for us in this day with all the accumulated knowledge of centuries, and with the most improved instruments and methods, to place ourselves back in the circumstances of these early old philosophers, upon whom, as regards these subjects, light and truth were just dawning. Yet they were not to be baffled. There was one man at least among them who rose to the occasion, and led the way for geodecists in all ages to the obtaining of the size of the earth. This was Eratosthenes. He was born in Cyrene, in B.C. 276, and because of his learning was placed in charge of the great library of Alexandria. His name should ever be honoured by geodecists and geographers as that of the man who first devised the scientific method of ascertaining the size of the earth by measuring an arc of the meridian. It is interesting

to note in passing that it is practically his arc that will form part of the great arc running from north to south through the entire continent of Africa, which is now being measured.

We will now see how Eratosthenes set to work to solve the question of the size of the earth over 2100 years ago.

Two places exactly north and south of one another must necessarily be on the same meridian, and the circle that passes through these places must be a great circle, that is, a circle that divides the sphere into two equal parts, and so measures its circumference. The problem, then, that Eratosthenes set himself, and indeed that which all geodecists have had to solve ever since, was the measure of the circumference of this circle. Eratosthenes noted the angle cast by the shadow of the gnomon of the scaph at Alexandria, when the sun was at the summer solstice; while at the same time he knew the sun to be vertical, and that the gnomon cast no shadow, at Syene (Assouan), which was assumed to be on the Tropic of Cancer: thus he found that the measure of the arc of the great circle between Alexandria and Syene was a fiftieth part of a great circle, or 7° 12′. The linear distance between these two places he took to be 5000 stadia, so multiplying the 5000 by 50, the proportion of the arc he had measured to the whole circle, he found the circumference of the earth to be 250,000 stadia. This, for some unexplained reason, seems afterwards to have been altered to 252,000 stadia.

It is impossible to say at this date how near the result he obtained was to the truth, but it could not have been very exact. In the first place there was an error in assuming that Alexandria and Syene were on the same meridian, for, in fact, there is about 3° difference between them; neither is Syene exactly on the Tropic of Cancer. Then no allowance was made for the diameter of the sun, and the measures were necessarily rough, so that altogether no great accuracy

could have been obtained. The stadium used by Eratosthenes has been assumed by some writers to have been one seven-hundredth part of a degree, so that, if we accept this value, with the 250,000 stadia, he found the circumference of the earth to be 24,675 statute miles, or about 200 miles smaller than it really is. However, it is more likely that he used the ordinary Greek stadium of 600 to a degree, in which case his result would be very much more in error. But it is quite impossible to say now what measures he really used, so, although we cannot tell how near he came to the truth, we can render him the honour he deserves as the leader of the way, and the father of geodetic science.

The next to attempt the measurement of the circumference of the earth, about two hundred years later, was Posidonius. He assumed that Rhodes and Alexandria were on the same meridian, and that the distance between these places was 5000 stadia, so proceeding on the same principle as Eratosthenes, except that he used the star Canopus instead of the sun, he found the difference of arc between these two places to be 7° 30′, or one forty-eighth of the complete circle, so 48 times 5000 stadia gave the circumference of the earth as 240,000 stadia. The use of a star instead of the sun was likely to give a better result than that of his predecessor, but here, again, so few particulars are known that it is impossible to say how near the real value the result actually came out.

As years went on, other attempts were made at solving the same problem, of which the most important of an early date was doubtless the interesting measurement made under the direction of the Caliph Almamon on the plain of Singar, in Mesopotamia. This was perhaps the most scientifically correct of any up to that time, that is, A.D. 819, inasmuch as the distances were measured by means of wooden rods, and the astronomical observations of the

star's meridian altitude were probably made with superior instruments.

So far, the distances between the two terminal points of the arc had been actually measured on the ground, or attempts had been made at measurements of them, and errors in these measurements, owing to want of proper alignment, undulations of the ground, and other difficulties, must have occasioned considerable inaccuracies in the results. However, in the year 1615, the Dutch mathematician, Willebroard Snell (or Snellius), introduced for the first time the system of triangulation now used by all surveyors and geodecists; and in his measurement of an arc in Holland, he connected the two terminal points, Alcmaar and Bergen op Zoom, by a series of triangles, observed azimuths (or true bearings), and computed the total distance by trigonometry, depending upon a carefully measured base-line. This marks an epoch in geodesy and surveying, and we owe to Snell a lasting debt of gratitude for his work, specially when we remember that he had to compute the whole of his triangulation without the use of logarithmic tables.

When the first measurements of arcs of the meridian were undertaken it was, of course, supposed that the earth was a perfect sphere, and no one thought about it being flattened at the Poles, or that the polar axis was less than the equatorial. However, as more accurate determinations were made, this fact became evident, and I will endeavour to show you briefly how it came about. Sir Isaac Newton, by his marvellous insight into the laws which govern the mechanics of the universe, had as early as about 1687 proved by mathematical theory that the earth, owing to its rotation on its axis, could not be a perfect sphere, but would take the form of an oblate ellipse, of which the equatorial diameter is slightly longer than the polar diameter. Owing to the effect of centrifugal force, those

portions of the earth's crust near the equator would, during the slow process of solidifying, tend to fly off, and thus make the earth take the form of an ellipse rather than a perfect sphere ; but so far, it was only theory, and theory is never very conclusive to most of us, unless it is supported by experimental proof. Many appear to consider it safer to have their facts first and then find a theory to prove them, than to propound a theory and wait for proof afterwards. However, Newton, like a true prophet, worked the other way, and having propounded his theory, waited in patience for some accurate measurements of the figure of the earth to be made which should verify his conclusions. Like most other great discoveries of the kind, this idea of an oblate spheroid of Newton's was subject to much criticism and scepticism, specially in France, and at first it was thought that the philosophers there had proved from their measurements that the earth, instead of slightly bulging out at the equator, took the opposite form, and had its longest diameter in the line of the polar axis ; but this was afterwards found to be due to errors in measurement, and Newton's theoretical figure for the earth was, with certain slight modifications, finally proved, by experiments and accurate measurements, to be the correct one. This question was set at rest early in the eighteenth century by two independent methods, that of actual measurement of arcs of the meridian in low and high latitudes, and by the different lengths of pendulum oscillations, due to the difference of gravity in different latitudes. Notwithstanding all the improvements that have been introduced since that date, these are still the two methods by which we obtain our knowledge of the figure of the earth.

Without going into detail I should just like to make clear how the spheroidal figure of the earth is obtained from the measurement of arcs of the meridian, and for

that purpose must refer to the three diagrams (Figs. 66, 67, 68).

The stars are all so distant that rays of light from them pass as parallel lines to the earth, no matter what latitude a man may be in. Let us, then, first suppose the earth to be a perfect sphere (Fig. 66), then it is clear that if we imagine a star to be exactly in the zenith, or over the head of a man at A in 30° north latitude, it will be 30° from the zenith of a man at B in 60° north latitude, 60° from a man at C at the pole, and so on. Further, since the figure is a sphere, the radii are of equal length, and the length of the arc subtended by each of the 30° would, if measured on the ground, be found to equal the same number of miles. If, next (Fig. 67), we imagine the earth to be a plane surface, then the rays of light from a star would subtend the same angle, no matter how many miles a man travelled north or south, since the vertical lines passing through the observer's position would be parallel with one another. It is evident, then, that if, as in Fig. 68, the earth's figure deviates from a perfect sphere and tends to flatten at the poles, the number of miles contained in a degree as measured on the surface of the earth will become greater as the equator is left and the poles are approached, inasmuch as the vertical lines, or radii of the arcs subtending

Fig. 66.

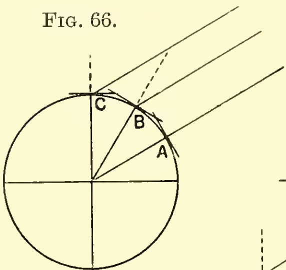
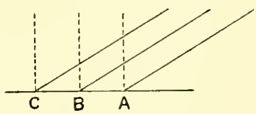


Fig. 67.



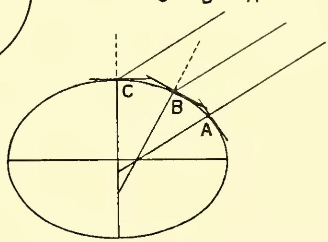


Fig. 68.

the same angle, increase in length ; and it is principally from this measured difference in the length of a degree, or certain number of degrees, that the figure of the earth has been determined.

As we have stated, another method of finding the true figure of the earth is by the increase of the effect of gravity

FIG. 69.—Most important accurately measured Arcs.

on the oscillation of the pendulum as the equator is left for higher latitudes. If the polar radius is shorter than the equatorial, the force of gravity, after allowing for increased centrifugal force at the equator, would be slightly greater at the poles than on the equator, since an observer would

be nearer the centre of gravity in the former positions, and this has been found to be the case. The ratio of the equatorial to the polar diameter of the earth deduced from the difference of gravity does not, as far as present observations go, differ sensibly from that obtained from terrestrial measurements of arcs of the meridian. However, we cannot now go into this matter further.

In recent times arcs of the meridian have been measured with the greatest care, in quite a number of different parts of the world, using the most accurate instruments and methods of computation. The map now before us (Fig. 69), which is on Sir Henry James's two-thirds projection of the sphere, shows the most important meridianial arcs up to date, as well as longitudinal arcs. The chief object of these measurements is, of course, to enable us to obtain a true knowledge of the form of the earth; but to do this thoroughly many other and much longer arcs should be measured. From measurements made during the last century, or since Delambre's determination of 1806, over a dozen different values have been given to the ellipticity of the earth. These range from $\frac{1}{286\cdot5}$ to $\frac{1}{334}$. The value lately accepted by us in England has been usually $\frac{1}{293\cdot466}$, which is the result of the elaborate calculations of Colonel A. R. Clarke, R.E., published in 1880. According to his investigations, the earth may be considered as an oblate spheroid of which the equatorial radius is 6,378,206·4 metres (3,963·3 stat. miles), and the polar 6,356,583·8 metres (3,949·9 stat. miles).

Strictly speaking, the figure of the earth does not appear to be a true spheroid, as certain measurements tend to show that the diameter in low latitudes varies slightly for the same parallel in different positions. This difference is, of

course, very slight, and so few accurate measurements have been made that it is impossible to say at present exactly how much it varies.

Since Clarke's results were published a considerable amount of fresh geodetic work has been done, and it is quite likely that his figures will be slightly modified when this is all investigated.

Before leaving this subject, I should like to call your attention to the excellent work now in progress of measuring an arc right across the continent of Africa from south to north, to which I have already alluded. Under the able superintendence of Sir David Gill, the late Astronomer Royal of the Cape, the southern part of this arc has been carried through the Cape Colony and Rhodesia, as far as you see the unbroken line (Fig. 69), and it is hoped that it will soon be continued along the pecked line. The Germans will undertake the section through their territory, the part west of Victoria Nyanza is already finished, and the line is to be continued down the Nile to the Mediterranean by the Egyptian Survey department. This will give a far greater length of arc than has been hitherto measured, and be of enormous value in geodetic work. If, as it is hoped, the line can eventually be carried along the coast of Palestine and Asia Minor, and so joined up with the European arc, the result will be most invaluable.

Voyages of any great length were unknown to the earliest navigators, who were content for the most part to follow round the coast-lines of the Mediterranean and neighbouring seas of the old world; for in those times, without the aid of a compass, and with only the roughest possible instruments, they rarely ventured far from land. True, as we have seen in the case of Pytheas, the discoverer of our own shores in the fourth century B.C., there were some of these old sailors who were also quite

learned scientists, and sufficiently well acquainted with the stars to make use of them for steering their ships, and fixing their positions approximately in latitude. But these were doubtless few, and by far the greater number worked entirely by "dead reckoning" as it is now called by navigators, obtaining rough estimates of their distances and direction, using landmarks, and never going further from shore than they could help. In this way, by repeated voyages, and making use of the experience of earlier travels, by degrees quite surprisingly good charts were drawn. Most

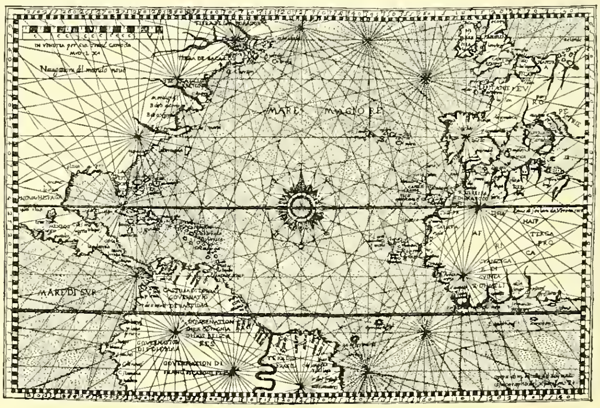


FIG. 70.—Chart of Atlantic, showing Loxodromic Lines.
(*From a chart of A.D.* 1565 *in Putnam's 'Nautical Charts.'*)

of them were covered with lines of bearings, or loxodromic lines (Greek λοξός, oblique, and δρόμος, a course), as they were called, for the guidance of navigators, like that here reproduced (Fig. 70). Down to the end of the fifteenth century of our era, even after the introduction of the compass, this was the only kind of hydrographic surveying and charting known.

I now show you (Figs. 71, 72) two outlines of the basin of the Mediterranean and neighbouring shores; one is from a recent chart, and the other is from the chart of the World by Juan de la Cosa, the pilot of Columbus, dated A.D. 1500.

You will see by comparing these how remarkably good some of these old charts were. Fig. 73 is another of a little later date of the coast of Africa by Diego Ribero of A.D. 1529. If you compare this with the modern map (Fig. 74) the general accuracy will be again apparent.

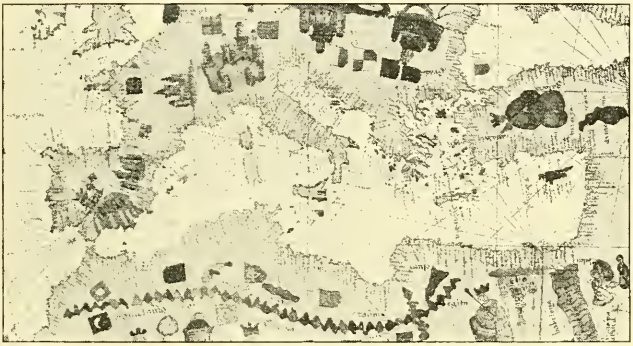


FIG. 71.—Mediterranean Sea (from Juan de la Cosa's chart, A.D. 1500).

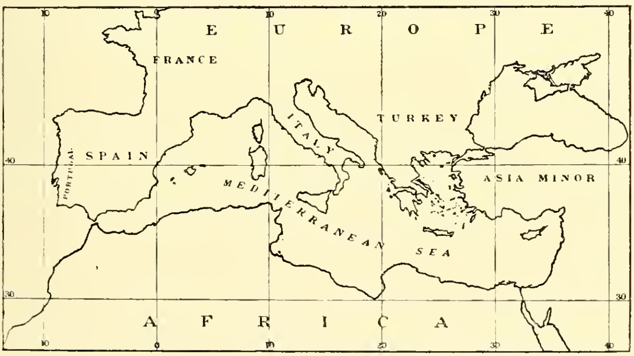


FIG. 72.—Outline of Mediterranean from Modern Chart.

These old charts were always far more out in longitude than in latitude, as navigators had in those days no reliable chronometers, and for the determination of longitude they had to rely on a rough estimation of distance, which was generally greatly exaggerated. Even now, longitude is much more troublesome to find that latitude, for the reason

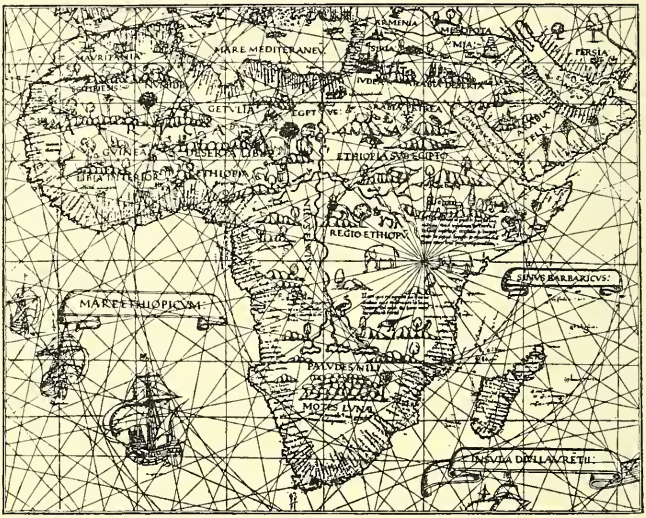


Fig. 73.—Africa according to Diego Ribero, A.D. 1529.

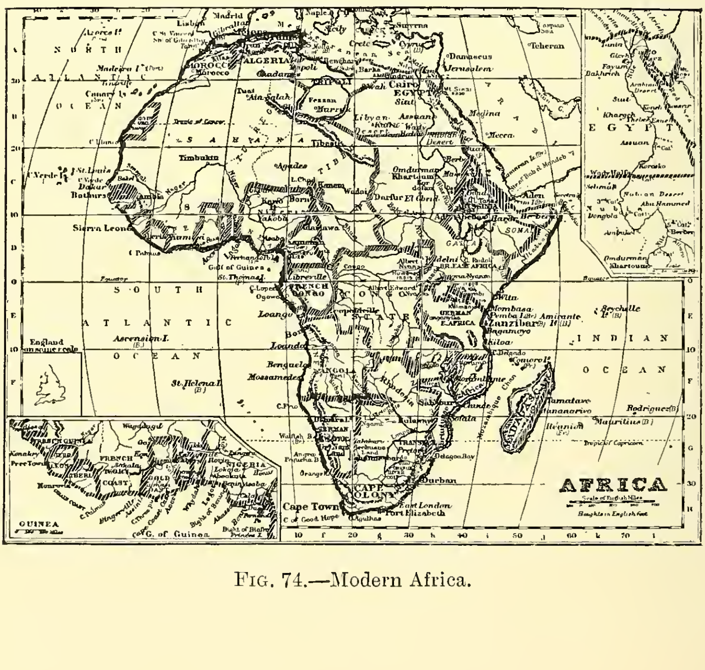


Fig. 74.—Modern Africa.

that there is no natural zero line from which it can be measured; whilst for latitude we have the equator, which serves this purpose.

We cannot dwell longer on these old charts, and the methods by which they were constructed, interesting though it would be to do so, and I must now give you a brief account of the survey methods of our time, referring occasionally to their development, as I pass on.

The basis of all good surveys is an elaborate system of accurate triangulation by which certain well-defined points, at suitable distances apart, are carefully determined. These triangles cover the country as a sort of network, to which the mapping of the intermediate topographical features are afterwards adjusted. The angles of all the triangles are very carefully measured with a theodolite, being repeated several times, and a good mean value of each obtained. The lengths of the sides, instead of being all separately measured, are obtained by trigonometrical computation from a measured line, called the base-line. I told you earlier in this lecture that the Dutchman Snell, in 1615, was the first to introduce this method of obtaining distances in a triangulation. Before Snell's time no one seems to have carried this idea out practically, and to him therefore all surveyors will ever be most grateful. As is always the case in such matters, it seems surprising that this was not done before, yet, although the principle may have been understood, so far as we know it had not been practically applied. Here is a map (Fig. 75) of the principal triangulation of the British Isles, and another one of the triangulation of India (Fig. 76). These will give you an idea of what is meant. The sides of the triangles computed from a measured base should, when the work is properly carried out, be more accurate than if they had been all separately measured, for to measure a long distance extending over 10, 20, or more miles, across

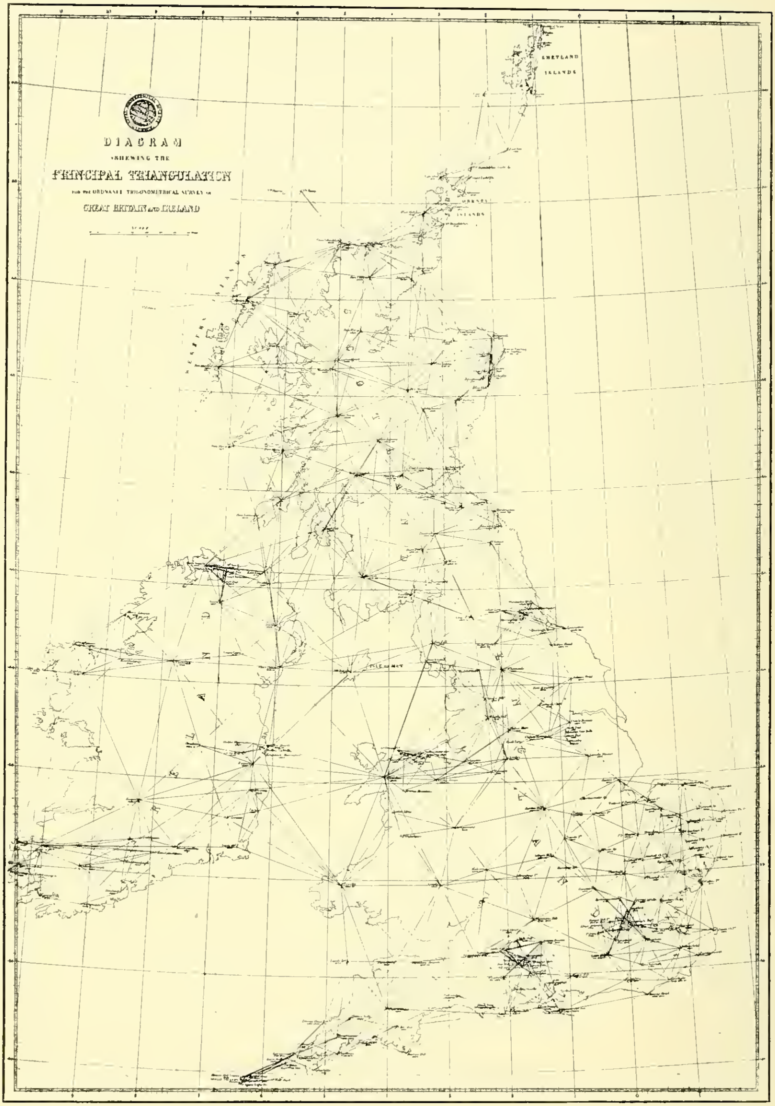


FIG. 75.—Triangulation of the British Isles.

uneven country, apart from the impossible time it would take, would, as you can imagine, be a most difficult business: but when only one base-line has to be measured,

it is quite different, and all the attention and care in distance measurement can be concentrated on this one line. When the triangulation extends over a large area additional base-lines are usually measured to check the work.

The measurement of a base-line for an extensive and important survey is therefore a most serious undertaking, and one that calls for the greatest skill and accuracy. The first base-line for the Ordnance Survey of England was measured by General Roy, on Hounslow Heath, in 1783, with wooden rods, tipped with bell-metal for end contact, and provided with plates of ivory on the upper surface near each end, on which were drawn fine lines for coincidence in measuring. The outside length of the bars was 20 feet 3 inches, and they were supported at each end by stands. After proceeding some time with the measurement of the base in this manner, it was found that the humidity in the air affected the length of the rods, and it was recommended by Col. Calderwood to substitute glass rods for them; but while these were being made, the whole base was completed with the wooden rods. The distance obtained from the two measurements agreed

FIG. 76.—India, showing Triangulation.

well, and it was announced that the true length of the line was 27,404·0137 feet at a temperature 62° Fahr. In 1791, the Ordnance Survey was placed under the charge of Col. Williams, Capt. Mudge, and Isaac Dalby, and their first task was the re-measurement of General Roy's Hounslow Heath base, which was now carried out with steel tapes. The result was most satisfactory, and agreed within three inches of the length previously obtained.

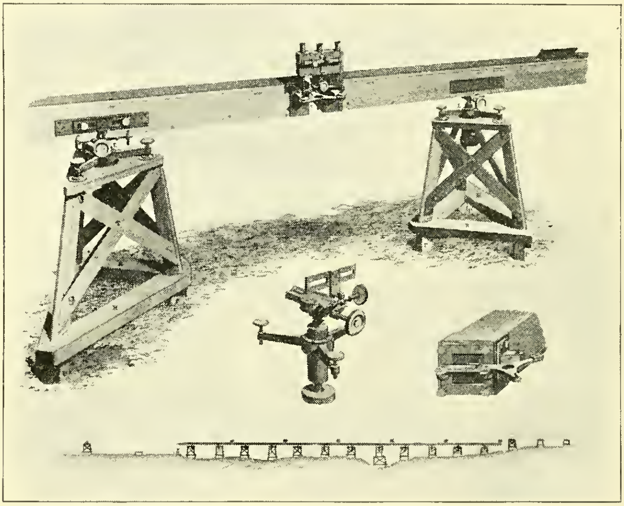


FIG. 77.—Colby's Compensation Base-Line Apparatus.

A new apparatus came into use later on for base measurement, designed by Colonel Colby, and used in the measurement of the Lough Foyle base in Ireland in 1827–1838; and the Salisbury Plain base in 1848. The difference between the measured length of the latter and its length as computed from the former was only 4·6 inches, although the distance between the two bases is something like 345 miles. A sketch of this apparatus is shown above (Fig. 77). It was called Colby's compensation apparatus, and consisted of a bar of brass and a bar of iron joined together at their

centres, but free to move the rest of their length. By a lever arrangement attached to the ends of the bars, owing to the unequal expansion of the two metals, small dots were kept at the same distance apart, whatever the temperature might be. The apparatus was further fitted with microscopes, and was supported by strong tripod stands.

From what has been said, it can be seen that to measure an accurate base-line is no easy matter, and occupies quite a long time. In addition to the actual measurement, correction has to be made for the slope of the ground, height above sea, and several other things, before the required accuracy can be obtained.

Other forms of apparatus for base-line measurement have been designed from time to time, and I am pleased to say that in recent years great improvements and simplification have been made owing to the introduction of *Invar*, an alloy of nickel and steel, of which measuring-tapes are now being constructed. This metal has such a small coefficient of expansion due to change of temperature, that it may be considered for all practical purposes to be unaffected by these changes, which greatly simplifies things. The latest base-lines have been measured with tapes or wires of this metal, and are considered most satisfactory. Fig. 78 is a view of one end of this apparatus. It is merely a long band of invar wound round a drum, and supported by tripods and pulleys at each end. To ensure the tension being the same, weights are suspended at the ends of a chain

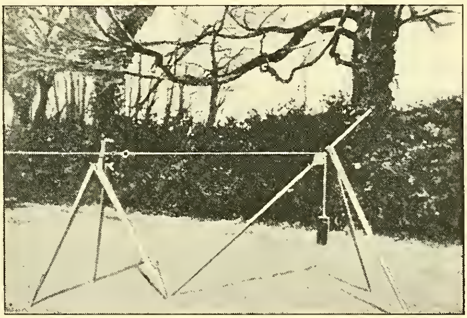


FIG. 78.—Invar Base-Line Apparatus.

by cords which pass over a pulley and are then connected with the invar tape itself. Various arrangements have been devised for marking the spot on the ground where the measurements begin and end, but this is generally done now by aligning with two theodolites.

It frequently happens in geographical work that it is impossible to measure directly a base-line of sufficient length to carry out the triangulation, and then an *extension base* is resorted to. This means that a comparatively short line, of say about a mile, is actually measured on the ground, and then this distance is extended by triangulation. AB is the

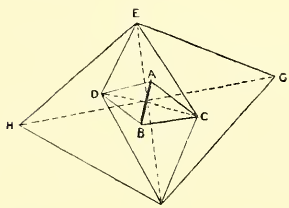


Fig. 79.—Extension Base.

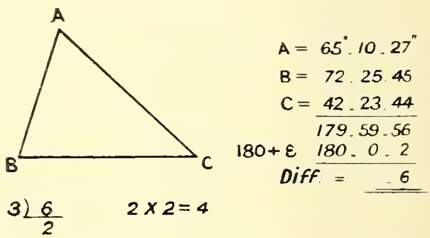


Fig. 80.

measured length on the diagram (Fig. 79), and this is first extended to CD, and finally to GH, by triangulation.

Having measured a base-line and taken all the angles with the greatest care, and many times over in different parts of the arc, to eliminate errors, the next thing to do is to adjust the angles preparatory to computing the sides of the triangles, and this is a lengthy business in an exact survey. In the first place, as no instrument is perfect, and no observer infallible, every angle is measured over and over again in different parts of the circle, and then the most probable weighted mean value accepted. After this various other conditions have to be taken into account, and the angles adjusted accordingly, on what is known as the principle of *Least Squares*, which like many other good

things in mathematics was first given to us by the famous German, Gauss. By way of a simple illustration, let us take the case of a single triangle (Fig. 80) of which the three angles have been carefully measured.

Now, we know by geometry that the sum of the three angles in any plane triangle must come to 180°, but since the earth's surface is curved, the angles measured must be regarded as those of a small spherical triangle, and in any spherical triangle the three angles exceed 180°, by an amount which, although extremely small in any triangle a surveyor is ever likely to measure, yet, when the sides are long, is quite appreciable. This small excess over 180° is called *spherical excess*. In a triangle of about 75·5 square miles in area, it amounts to one second, and it varies directly with the area of the triangle.

Returning now to our diagram (Fig. 80) we see that the sum of the three measured angles comes to only 179° 59′ 56″, whereas, allowing two seconds for spherical excess, it should have come to 180° 0′ 2″, therefore there is an error of minus six seconds. This is the total error in the whole triangle, but how are we to split this error up, and apply the corrections among the individual angles in such a manner as to ensure the most probable result? This is done by the rule of least squares, which means that, knowing the total error, or residual, we must so apply the corrections to the individual angles that the sum of their squares must be a minimum, or the least possible. In the case of a single triangle this rule is satisfied by dividing the total error into three equal parts and applying a third to each angle. This will be clear by considering the simple example before us. Here the total error or residual is six seconds; this divided by three gives a correction of two seconds to be added to each angle. Now, to prove that this is in accordance with the rule of least squares, let us square the

corrections applied, and $2 \times 2 = 4$, and 3 fours added together equal 12; therefore the sum of the squares of the corrections here is 12. If we try any other arrangement of this total error of six seconds, we shall find that the sum of the squares of the corrections will always be greater than 12. For instance, say we give the angle A a correction of 3 seconds, B 2 seconds, and C 1 second; then, by squaring these corrections, we shall have $9 + 4 + 1 = 14$, and so whatever other arrangement of the six we adopt.

I give this very simple illustration, merely that you may have some idea of what the rule of least squares means, but in real work there are many conditions to be satisfied, and a large number of triangles whose angles are inter-dependent upon one another. All these inter-dependent angles have to be adjusted so that the sum of the squares of their corrections is a minimum, and the sum of the corrected angles in each triangle is equal to 180° plus the spherical excess of that special triangle. There is also another condition to be satisfied, and that is that in any series of triangles the sines of the angles, if correct, are in proportion to the opposite sides, or the sines of the opposite sides in the case of spherical triangles. This other condition then has to be satisfied as well, before we can say that we have the most probable values of the angles. In fact, we have finally a long series of simultaneous equations to be solved, the computation of which becomes most tedious.

Having now obtained the best and most probable values for the angles of the triangles, all that remains to be done is to compute the lengths of the sides by the ordinary rules of trigonometry.

Whenever it is thought advisable, check bases are measured in the triangulation.

It is not necessary to go to all the trouble of adjusting by least squares, unless the triangulation is a very important

one, and the angles accurately taken with a first-rate theodolite. In ordinary geographical work, all that is usually done is to distribute what few seconds of error may exist equally among all the angles, and correct accordingly.

In triangulation, and other kinds of survey work, it is necessary to erect beacons or marks at the stations, which can be readily seen from other points of the survey, and I now show you one or two of these (Figs. 81, 82). These are of various forms of construction and design, and of course

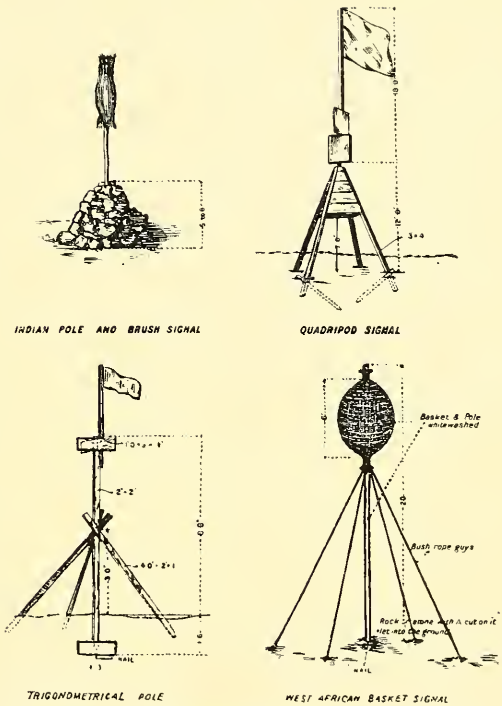


FIG. 81.—Triangulation Signals and Beacons.
(*From 'Text-Book of Topographical and Geographical Surveying.'*)

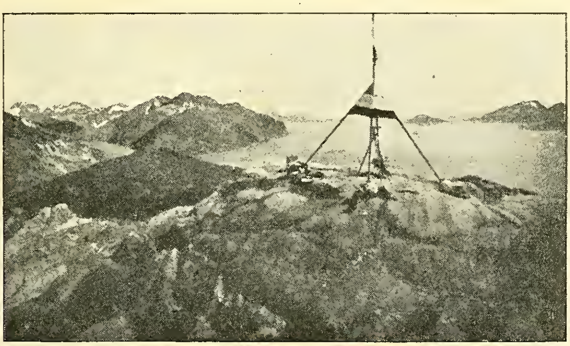


FIG. 82.—Survey Beacon, Alaska.
(*From Putnam's 'Nautical Charts.'*)

the important thing is to ensure their being readily visible at a distance. One of the best methods of marking stations is by flashing signals with the heliostat (Fig. 83). The next figures (Figs. 84, 85) show triangulators with theodolites at work. The surveyor has to be a man of great resource, and many expedients are resorted to in fixing up a theodolite in a favourable position for taking a round of angles. The man in the photograph (Fig. 86) is one of the United States Government surveyors, and he seems to be having a difficult time of it with his theodolite perched up in a tree.

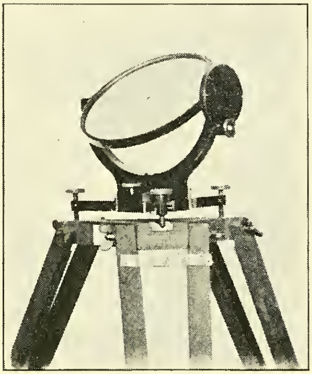


FIG. 83.—Heliostat.

Triangulation such as before described should form the basis of every good map; but, as you can imagine, it is a lengthy and expensive process. The rate of progress and cost naturally varies with the character of the country, the distance the stations are apart, and many other circumstances.

FIG. 84.—Triangulator at Work with Theodolite (U.S. Coast and Geodetic Survey).
(From Putnam's 'Nautical Charts.')

Although triangulation is the most exact system of surveying, there are others, such as traversing and plane-tabling, which I must tell you a little about later on, but I think I should first try to give you some idea of how the positions of places upon the earth's surface are determined from astronomical observations.

A triangulation or a traverse may be complete in itself

FIG. 85.—Surveyor at Work at Tree Station, Sierra Leone.
(*From 'Text-Book of Topographical and Geographical Surveying.'*)

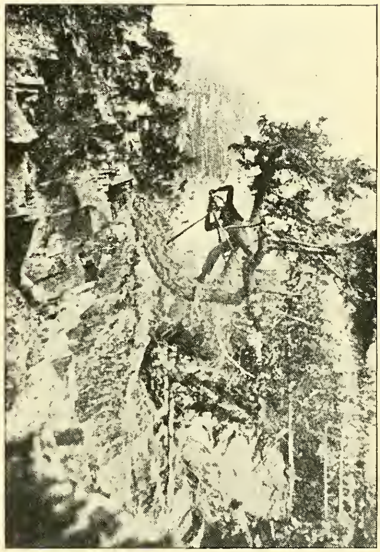


FIG. 86.—Surveyor at Work with Theodolite in Tree.
(*From Wilson's 'Topographical Surveying.'*)

and furnish a map of a special area concerned, but it will not tell us where the area, or any special spot on it, is on the earth's surface, nor the position it occupies with regard to other places outside its own limits. To ascertain this we must know the latitude and longitude of the place, and, to be correct, also the height above sea-level as well. However, we will leave the latter for the present and confine our attentions to the simple methods of finding latitude and longitude.

The idea of indicating the positions of a place by latitude and longitude, as we have seen, dates back to the time of the early Greek philosophers.

To any one entirely unacquainted with these subjects, it is at first surprising that, if you could blindfold a man, and take him to any spot on the earth's surface, say somewhere in the middle of Africa, and then remove the bandage from his eyes, he could, provided he had a few instruments and books, show you on a map, in a short time, the exact spot upon which he stands; that is, if he has a clear sky and is not bothered by clouds as, alas! we are so often in this country.

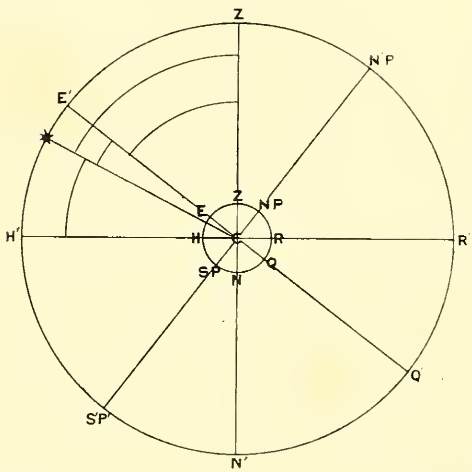


Fig. 87.—Finding the Latitude.

First of all let us take the latitude, and consider the principle underlying one of the simplest ways of finding it. If we regard the earth as a perfect sphere, the latitude would be the angle that a line from the place where a man stands makes with the plane of the equator at the centre of the earth. A glance at the diagram (Fig. 87) will perhaps help to make this clear. Here the circle in the centre represents the earth, of which the line EQ is the equator, and the line at right angles to this the axis of the earth, with its terminal points NP and SP, the north and south poles respectively. The circle outside is the meridian, or north and south line in the heavens, passing through the zenith Z′, or the point in the sky exactly over the head of a

person on the earth at Z, and H′R′ the rational horizon. The plane of the earth's equator projected to the heavens will be represented by E′Q′. The line joining the position of a person at Z to the centre of the earth is shown by ZC, and it is clear then that the latitude of the place where he stands is the angle ECZ, or the corresponding angle in the sky E′CZ′. This then is the angle that we have to measure. If we could by some means or other continue the plane of the earth's equator away into the sky, and mark this great circle amongst the stars, it would help matters considerably, for all that would then be necessary would be to measure with a theodolite the angle subtended by the arc of the meridian between the zenith and this line in the sky. But no one, so far, has been able to paint this much-needed circle for us, so we have to do the next best thing. There is a most wonderful book called the 'Nautical Almanac,' which is absolutely indispensable to the navigator and geographical surveyor. It may not strike a person taking it up for the first time as quite so interesting as an up-to-date novel, and, like most really good things in this world, it has to be understood to be appreciated. Amongst much valuable information it contains is the distance, in angular measure, of stars, the sun, and other heavenly bodies, from the celestial equator, or, as it is called, their declination. In fact, it just gives us what we want for finding the latitude angle ECZ, for, as you will readily see, if we cannot measure the angle from the zenith down to the equator in the sky straight off, we can now do it in two pieces. When the star or the sun is on the meridan we can easily measure with a theodolite or sextant how many degrees, minutes, and seconds it is from the zenith (the angle Z′C✶), and then, by adding or subtracting the angle that the star is from the plane of the celestial equator, or its declination given in the

'Nautical Almanac,' we can find how far the zenith is from the equator, which, as we have seen, is the latitude. Instead of measuring the zenith distance Z′C*, as can be done with a theodolite or zenith telescope, it is more usual to observe its complement, or the altitude angle H′C*, and afterwards subtract this from 90°, which of course comes to the same thing. Stars both north and south of the zenith are observed, and in what is known as Talcott's method, which is the most accurate, the zenith distances of stars which pass the meridian very near the zenith only are used, so as to eliminate errors of refraction as well as of other kinds.

This will, I hope, give you a general idea of how the latitude of a place is obtained. There is much more I should have to tell you about it if I had to take you as pupils, but we cannot go further in a short lecture of this kind.

You often see in text-books that the latitude of a place is the altitude of the pole above the horizon. Well, a little consideration will show that this is correct, for the angle N′P′, C, R′, the altitude of the Pole, must be equal to the angle E′, C, Z′, the latitude, so if we had stars exactly over the poles of the earth, their corrected measured altitudes would be the latitudes; but I regret to say that here again astronomers have not been so obliging as they might have been, for no such stars exist. Even our so-called Pole-star is more than a degree away from the Pole; still, by applying corrections we do use this star for finding latitude.

Before I leave this important question of latitude, I must make one matter clear. We have so far supposed the earth to be a perfect sphere, so that lines at right angles to the tangent at any position on it would pass through the centre; in fact, the latitude we have considered is what is called the geocentric latitude. Now, since the earth is not quite a sphere, but spheroidal in form, it is

clear that the lines at right angles to the tangent at different parts of the curved surface upon which our angular measurements depend, will not pass exactly through the centre, except at the Poles and Equator. The latitude, therefore, by astronomical observation is really the angle λ instead of λ' (Fig. 88), the geocentric latitude. Irregularities in gravity seriously affect all observations of this kind by deflecting the plumb-line, or level, but the latitude resulting from an astronomical observation is in fact the angle between the direction of the plumb-line and the plane of the equator.

With ordinary care and a good theodolite, the latitude of a place can be found by direct observation with an error not exceeding $1''$ to $2\frac{1}{2}''$, except in places where the plumb-line is abnormally affected by inequalities of gravity, and this is much the same thing as supposing a man to commence measuring with a chain at the equator and continuing along a meridian till he reached the latitude of London ($51° 30' 30''$) through 3562 stat. miles, with only an error of 100 to 250 feet at the end.

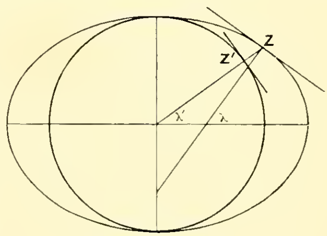


Fig. 88.

But latitude alone will not fix the position of a place on the earth's surface; it will only tell us how far the place is north or south of the equator. What is wanted now is some means of telling how far the place is east or west of some initial starting-line, at right angles to the other line, and this we have in the longitude. Now here we are met with a difficulty, for, as I said before, there is no line marked out by Nature from which longitude can be measured, as is the case with the latitude, for which we have the equator; so we have to find the longitude

another way, that is, by the difference of time between places.

The earth turns on its axis once in twenty-four hours, so that one hour $= \frac{360^\circ}{24}$, or 15°; thus all the meridians pass round from west to east, one after the other, in twenty-four hours, so that when the sun is on the meridian at any one place, say Greenwich, at 12 o'clock Greenwich Apparent Time, it will be on the meridian of another place 15° west an hour later, or, in other words, when it is 12 o'clock at Greenwich, it is only 11 o'clock at a place 15° west of Greenwich, and 10 o'clock at a place two hours or 30° west; whilst at a place 30° east of Greenwich it would be 2 o'clock in the afternoon.

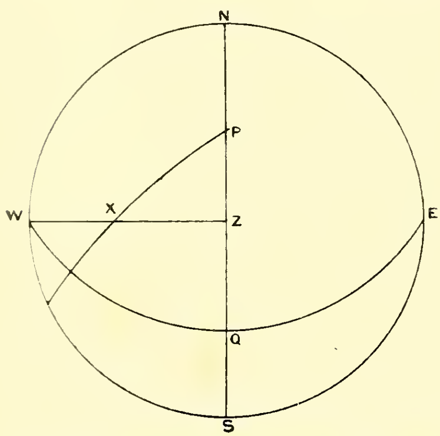


Fig. 89.—Finding Time from Altitude of Sun.

From this it is clear that the difference of longitude is only the difference of time between places, and if by an observation a person can find the time at a place where he is, and then by some means, such as by chronometer or telegraph signal, know the time of another place at the same instant when his observation for local time is observed, he has found the difference of longitude between the two places.

There are quite a number of ways of finding local mean time, both by the sun and stars, but I must content myself with briefly describing one of the most usual methods, and for this purpose I must direct your attention to the diagram (Fig. 89) which represents a celestial hemisphere projected

on the horizon of a man on the earth beneath the point Z. Let the circle NESW represent the horizon line, Z the observer's zenith, P the north pole, EQW the equator, QZ the latitude of the place of which ZP is the complement, X the sun, PX the north polar distance of the sun obtained from its declination, ZX the sun's zenith distance obtained from the measured altitude, WX; then, in the spherical triangle XPZ, the three sides are known, and the angle P can be computed. This angle will give the distance in time of the

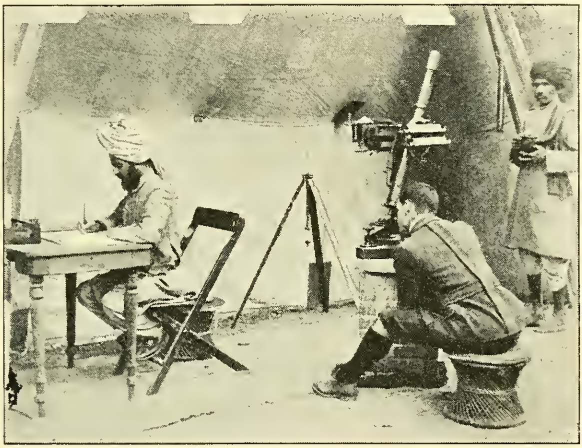


Fig. 90.—Indian Government Surveyor taking Observations.

sun from the meridian, or, as it is called, the sun's hour angle. Now, we know that when the sun is on the meridian of any place, it is Apparent Noon at that place, therefore, as we know the hour angle, or how far the sun is from the meridian, we have local apparent time, which, with the Equation of Time taken from the 'Nautical Almanac' applied, gives local mean time. In Fig. 90 we see an Indian Government Surveyor observing altitudes of stars, while Fig. 91 is a traveller in West Africa taking an observation for time with a sextant and artificial horizon. At sea several chronometers are carried

on board ship, rated to go Greenwich mean time, and then the officer takes an observation to find the local mean time, the difference giving him the longitude east or west of Greenwich. On land, it is not at all easy to carry the time, on account of the difficulty of transporting chronometers without the rate varying with jolting and change of positions, so now all we usually attempt to do by this means, is to get short differences of longitude between places along the route. When there is a telegraph wire, of course it is easy to send the time of one place to another, and perhaps wireless telegraphy

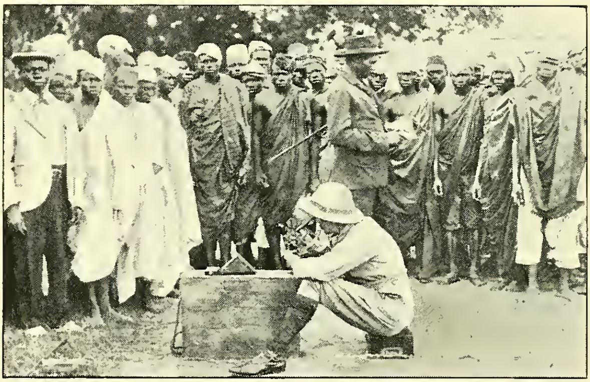


Fig. 91.—Observing with Sextant and Artificial Horizon.

will soon come to our aid in finding longitude, but so far it has always been a troublesome business, on land especially. In reckoning longitude, we might start from the meridian of any place, and in fact all sorts of initial meridians have been selected by different nations at various dates, each, I suppose, feeling that it would be right to take the meridian passing through its chief city or observatory. This, after all, was a mistake, and has led to unnecessary trouble with computations, so I am glad to say that most of the important nations have now decided to adopt the Greenwich meridian as their "prime meridian," as it is called.

In early days, before correct timekeepers were made, it was impossible to find the longitude with anything like accuracy, and all that seems to have been done was to estimate it from the distance travelled east and west.

There are what are called *absolute* methods of finding the longitude; methods by which the Greenwich mean time, or the time of whatever prime meridian may have been selected, can be found as well as the local mean time; and so long ago as B.C. 150 Hipparchus suggested a method of doing this by lunar eclipses. All of these methods, with the exception of that of eclipses of Jupiter's satellites, depend upon the motion of the moon. The moon moves round the earth once a month, and its exact position in the heavens is given in the 'Nautical Almanac' for every hour of Greenwich mean time. If, then, it is possible for a person to find at any instant where the moon is precisely, or how far it has travelled round the earth—in other words, its Right Ascension, he can turn up the 'Nautical Almanac,' and by a simple proportion sum find the Greenwich mean time, and then if he has taken the ordinary observation for local mean time at this instant, the difference is the difference of longitude. The best known of these methods are the Lunar Distance, Moon Culminating Stars, Moon's Altitude, and Occultations of Stars by the Moon; the former of these methods, which was first proposed by Werner in 1514, and Gemma Frisius in 1545, was quite commonly employed at sea before chronometers were as perfect as they are now, and longitude by this observation were observed by William Baffin, Captain Cook, and many other old navigators. It was specially applicable to sea use, as the angular distances between the moon and star or the sun could be measured with a sextant. With the exception of the Occultation, nearly all of the absolute methods have practically died out now, as the results were not near enough for modern survey requirements.

And, after all, this is not to be wondered at, for they come pretty much to the same thing as trying to find the exact time to half a second by a big-faced clock, with no minute or second hands, only an hour hand making one turn round the face of the clock in a month.

I have worked out hundreds of all these so-called absolute methods in past years, and if they came within five miles of the true longitude, they were considered quite good. Well do I remember having to compute some lunar distances, by a famous explorer, whose name I will not mention, but who was supposed to be near Victoria Nyanza at the time, yet if you had only his lunars to go by, he might have been anywhere between the east coast and halfway down the Congo.

Another very important observation for geographical surveyors is that for obtaining the Azimuth, or true bearing, of any one point from another. In the triangle PZX (Fig. 89) if instead of finding the angle P, as we do for local time, we compute the angle Z, it is clear that we shall have the true bearing of the sun from the north point of the horizon at the time that its altitude was observed, and by adding to this, or subtracting from it, the horizontal angle between the terrestrial point measured at the same time with a theodolite, we shall have the true bearing of this point. There are various other ways of finding azimuth, such as placing a theodolite in the meridian and measuring the angle straight off, but this is the method usually followed by travellers.

There is a system of surveying called Latitude and Azimuth traversing, which is very rapid, and under favourable circumstances surprisingly accurate. When time does not permit of carrying out a proper triangulation it is often most serviceable in unsurveyed regions, but it is useless when the route runs anything like east or west, and is only

suitable where there is a long distance between the stations, say fifteen or twenty miles at least. This system consists of observing the latitude of some prominent station, and the true bearing or azimuth of another, and then proceeding to the second station to which the bearing has been observed and taking the observation for the latitude of this. The two latitudes and the azimuth will enable one to compute the difference of longitude between the two stations, the distance in feet between them, and the difference of azimuth. The diagram now before you (Fig. 92) will help to make this clear. Here the latitudes of A and B are observed, as well as the azimuth or bearing of B from A, then in the triangle ABC with the side AC (the difference of latitude), and the angle A (the azimuth of B from A) known, the side AB, which is the distance between the two stations, BC the difference of longitude, and the small angle EBD the difference of azimuth due to convergency of the meridians, all can be computed.

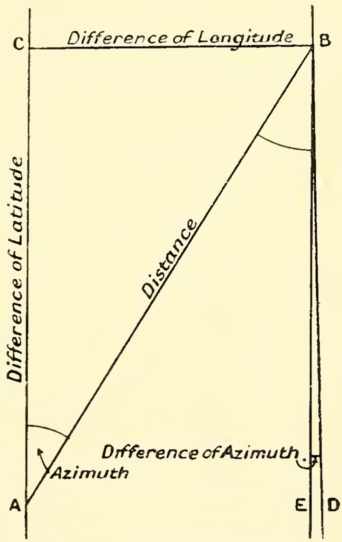


FIG. 92.—Latitude and Azimuth Traverse.

Allowance is made in the special table used, for the figure of the earth. This kind of survey is often carried on, when time is pressing, in open country, with prominent points, and is certainly the next best method to triangulation for this kind of work. It can be extended from point to point, and with rounds of angles taken at the various stations forms an excellent framework for filling in with a plane-table, or other instruments afterwards. A specimen of a latitude and

azimuth traverse is given in the route map (Fig. 93). This was made by one of my pupils, Mr. Talbot, of the

FIG. 93.—Map from a Latitude and Azimuth Traverse.

Alexander-Gosling expedition, and shows their route to Lake Chad.

In ordinary theodolite traversing, as it is called, the angles between the stations on the route followed are observed by a theodolite, and the distance between the stations measured with a steel tape or chain, correction being made for the slope of the ground traversed. When this sort of route survey is carefully carried out, and adjusted for errors, the result is very satisfactory, although it can never compare with exact triangulation. In thickly wooded country, when no distant points are visible, such as many parts of West Tropical Africa, it is practically the only way of making anything like a correct map. Lines of traverses are run in all directions through the forest-clad country, and checked as often as possible by crossing one another, and any other means available. Here (Fig. 94) is a photograph of a boundary commission surveyor in South America running a traverse with a theodolite through dense forest. The Gold Coast, Lagos, and other parts of West Africa are now being surveyed in this manner. Fig. 95 is a photograph of a part of one of the sheets of the new Gold Coast Survey made in this way.

Fig. 94.—Theodolite Traversing in Dense Forest.
(*From photograph supplied by Major P. H. Fawcett, R.A.*)

In the early days of African exploration, as indeed of other parts of the world, all that could be attempted by the pioneer, who pushed his way hurriedly through the unknown regions for the first time, was a rough compass route traverse checked wherever possible by astronomical observations for

latitude, longitude and azimuth; and although some of these were decidedly rough, it is surprising what good work was frequently carried out in this manner. At the principal windings of the route compass bearings were read, and distances obtained, usually by time, or some other approximate way. The route maps of Livingstone, Speke, Grant, Burton, Stanley, and others, were all made in this way, and if you were to compare some of them with the latest

Fig. 95.—Reduced from Sheet of Gold-Coast Survey, from Theodolite Traverses.

maps, you would be struck with their general accuracy. I will now show you (Fig. 96) a facsimile of part of Dr. Livingstone's map of his route across Africa in 1856, which resulted in the discovery of the Victoria Falls, with the latest map of the same region for comparison (Fig. 97).

Here (Fig. 98) is a page from a field book of a prismatic compass traverse, with the plotting of this section of the route opposite (Fig. 99). The position of the station F,

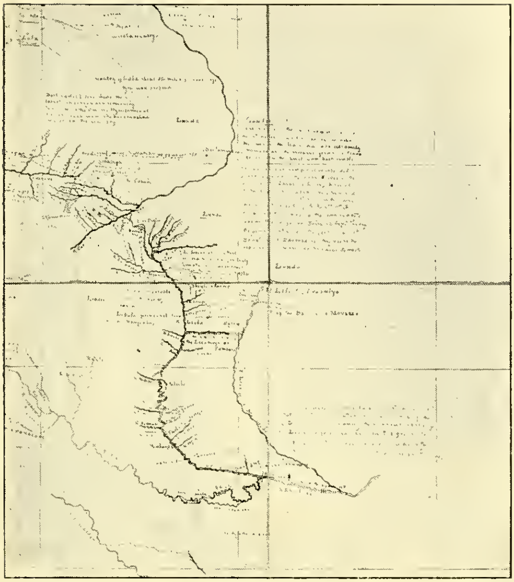


FIG. 96.—Map of Part of Central Africa, by Dr. D. Livingstone.

FIG. 97.—Recent Map of same Region as shown on Fig. 96.

is found to be in error, and according to latitude and azimuth observations it should be at F′, consequently the route is replotted, as shown by the upper traverse line.

In the last lecture a good deal was said about the plane-table and its development, but I must tell you briefly how this instrument is used in surveying. A plane-table is an excellent instrument for filling in the topography between

Specimen of Field Book of Prismatic Compass Traverse.

	h. m.	°	Miles per hour.	
		F KAMURA.		
Back Bearing to Buro Mt. 167° 30′	2 58	306 0		
			2·75	
		E		
	1 40 1 31	46 30		Bearing of hill 91° 30′
River crossed running W.	12 7			
			2·5	
		D		
	10 55 10 47	301 0		
			2·75	
		C		
NOTE.—When the route passes through thickly wooded country the bearings will necessarily be taken at much more frequent intervals of time than shown here.	9 5 8 57	0 30		Bearing of hill 55°
			2·75	
		B		
	7 30 7 26	312 30		
			2·5	
		A BURO MT. June 17 1905.		Bearing of hill in distance 27° 30′
F B to Kamura 347° 30′	6 0			Back Bearing to last Camp 139°
	h. m. *Times.*	*Magnetic Bearings.*	(Miles per hour.) *Rates.*	

FIG. 98.

points that have been definitely fixed beforehand and laid down on the board. The great difference between this method of mapping and any other is that instead of taking angles and recording them in a book, and afterwards replotting them, the map is actually drawn in the field, as the survey progresses, which has decided advantages. Fig. 100 is a specimen of an Indian surveyor's plane-table sheet. The principle is that of constructing similar angles

and figures, and to make it clear I must refer you to Fig. 101. The plane-table consists, in its simplest form, of a board on a tripod stand, and a ruler called an alidade, for sighting on to distant points. Let it be required to make a plan of the district shown on diagram. To begin with, a base-line is measured, and the plane-table set up

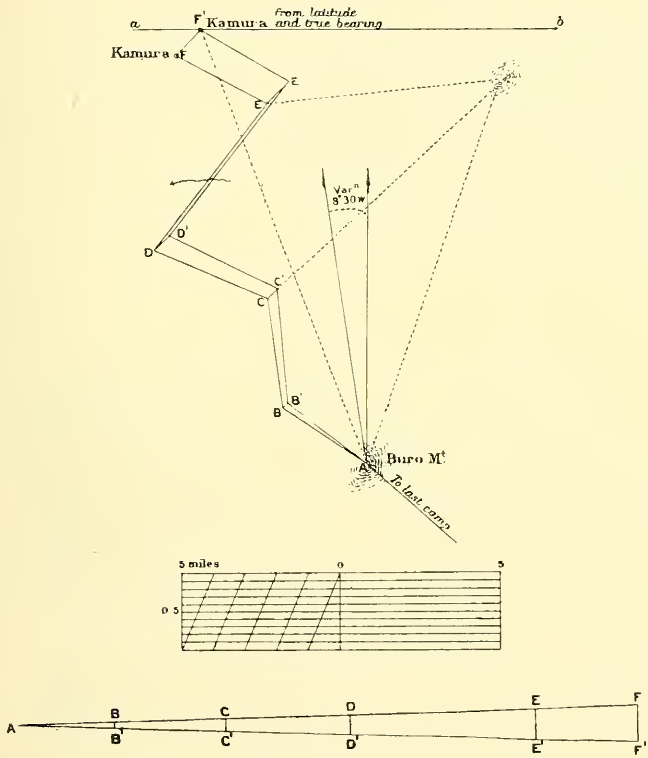


FIG. 99.—Plotting of Prismatic Compass Traverse.

at A, one end of this base. Then the alidade is sighted on to B, the other end of the base, and a line drawn on the board to any suitable scale to represent the base-line. With the alidade on the point A, all definite points in the country are sighted, and lines are drawn

towards them. Next the plane-table is moved to B, the other end of the base. The alidade is placed along the base-line, and the plane-table and alidade together turned on to A. The board will now be oriented, as it is called, that

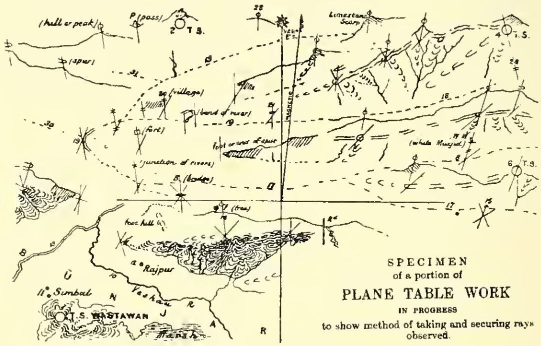


FIG. 100.

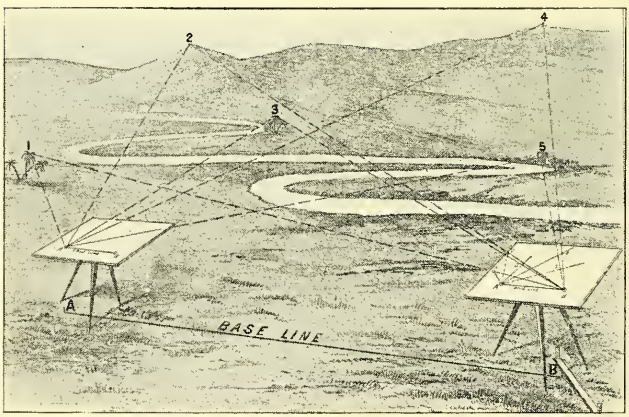


FIG. 101.—Principle of Plane-Tabling.

is, placed with its sides in the same directions of the compass as they were at A. This orientation is frequently made with a magnetic compass needle. Now, having oriented the table, fresh rays are drawn to the same points to which rays were drawn at A, and you will see at once that the points

of intersection of the lines drawn from B with those previously drawn from A will fix all these points on the plane-table. This, in a few words, is the simple principle of plane-tabling, but there is a lot more to be said on the subject which we cannot go into now. One of the chief things to learn is to be independent of the compass needle, and to orient and fix one's position by means of points already laid down on the board. All this I have fully explained in the Society's 'Hints to Travellers.'

Many attempts have been made to introduce a really practical method of photographic surveying suitable for travellers; but so far it must be admitted that these have not been attended with any great measure of success, although a good deal of survey work has been done by photography for years past. Of all the systems, that described by Capt. F. V. Thompson, R.E., in the *Geographical Journal* for May last, is the most promising, and it is hoped will prove more accurate, rapid and altogether more practical than those of its forerunners. Those interested in the subject should read this paper for themselves. Two photographs of the same distant view are taken, one from one end of a measured base, and one from the other, means being provided for placing the instrument, when at the second station, exactly parallel with its first position; then, from the apparent displacement due to parallax, the positions and distances are found. Photographic surveying is specially suitable for filling in detail in a mountainous country; and indeed for this purpose I have often found ordinary photographs quite serviceable. For making rapid plans during military operations, photographic methods have for years past been tried, and I was told by an officer not long ago of some experiments he saw on the Continent of photographing from a kite. A kite was sent up with a special camera, and when it was in the air a button was

touched by some one below. Immediately, by an electric arrangement, a photograph of all that was beneath the kite was taken, and as the kite descended this photograph was automatically developed and printed, so on its reaching the ground there was quite an intelligible plan of the field of operations. After this I don't think I need say more on this subject.

I must now bring this lecture to a close by a few general remarks on finding heights. No survey is complete that does not give some idea of land relief, or the heights of the principal and characteristic features included. Not only should the heights of the hills and mountains be given, but that of valleys and plains as well, so that the relative relief of the country may be known. Now, in reality all the various methods of finding heights may be classed under one of two headings: they either depend upon vertical angles computed by trigonometry, or on the observed change of the atmospheric pressure. Under the first heading may be classed ordinary spirit-levelling, if we consider the vertical angle zero, as well as what is generally known as the theodolite vertical angle method; and under the second, heights by mercurial barometer, aneroid and boiling-point thermometer. Of the two principles the former gives the best results, and on any large survey the heights are found by careful spirit-levelling. This, though requiring great care, is simple in principle. The level, which is like a theodolite telescope with a long level on the top of it, and mounted on a tripod stand, is set up at A (Fig. 102). The levelling staff, divided into feet and inches, is then taken to the points 1, 2, 3, 4, etc., and the difference of the readings as seen on the cross wire of the telescope gives the difference in height between the various points. The level is then set up at B, and the operation repeated there, then to the next station, and so on. By placing a level in a position midway

between the stations as shown, errors due to refraction and other causes are eliminated.

Heights by theodolite vertical angle method means setting the theodolite up at a known station A (Fig. 103), and taking a very careful vertical angle to a distant point B, of which the height has to be found, and of which the distance is known. Then, if the earth were a plane surface, the difference of height between the two stations, as may be seen (*a*), would be the distance multiplied by the tangent of the vertical angle. However, since the earth's surface

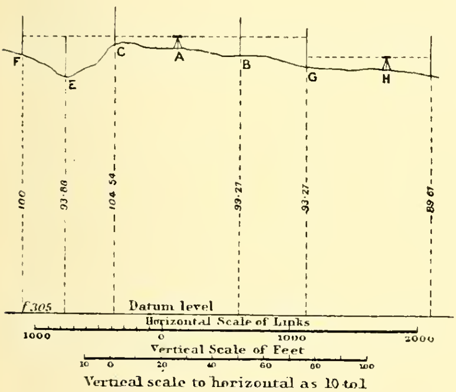


FIG. 102.—Levelling.

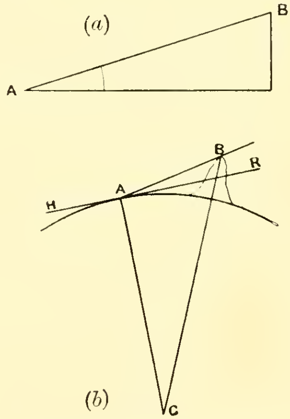


FIG. 103.—Heights from Theodolite Vertical Angles.

is curved, this would not be correct, and if the distance is great the resulting difference of height would be considerably in error. Correction has to be made, therefore, for the curvature of the earth, and to a lesser degree, for the refraction of the atmosphere. The diagram ((*b*) Fig. 103) is intended to assist in making this clear. Let C be the centre of the earth; then the line HR would be the horizon line of a man at A, and the vertical angle measured will be the angle BAR. The consequent difference of height computed by the tangent of this angle will be only BR, which

is clearly not much more than half the height of the mountain above sea-level, and a large correction must be applied to get the true height. If reciprocal angles could be taken, that is the back angle to A from B as well as the angle to B from A, then the depression angle at B would be just as much too large as the elevation angle at A is too small, and the mean of the two would be the correct angle. If both are depression angles, as they may be in rare cases when the difference of height is small and the distance very great, then half the difference of the two angles is the correct angle.

The method of finding difference of height, or height above sea-level, by the difference in the pressure of the atmosphere was first proposed and carried out practically in France by Pascal, in 1648, five years after the invention of the barometer by Torricelli, and since his time has been constantly in use in one form or another. In principle it is simple enough, but owing to the difficulty in obtaining the exact data required is, like so many other things, not so easy in practice. At sea-level the mean pressure of the atmosphere is something like 16 lbs. to the square inch, and as it diminishes in the inverse ratio of the square of the height above the sea, the difference in the pressure soon becomes apparent as one ascends. In principle, then, if there were no complications, and no temperature corrections, etc., all that would be required to obtain the difference of height between any two points, would be for one person to read a mercurial barometer at the sea-level, and another at the top of the mountain at the same time, then from this difference compute the height. In practice it does not work out so easily as this; temperature has to be allowed for, and all sorts of difficulties arise which I must not go into now. An aneroid is only a portable barometer which registers the difference of atmospheric pressure by

means of a vacuum chamber balanced by a spring, instead of by the height of the mercury. Owing to its portability, it is generally carried by explorers, but the resulting heights are not at all reliable. The boiling-point thermometer again is only a different kind of barometer. Water boils at sea-level, when the mean pressure is roughly 30 inches, about 212°, and at great heights, where the pressure is much less, it will boil at a lower temperature: at 1400 feet, for instance, it is something like 186°. So here, then, we have another way of computing the difference of heights. On the route maps of early explorers, and indeed frequently at the present time, the heights depend upon aneroid and boiling-point readings, but they are never very reliable.

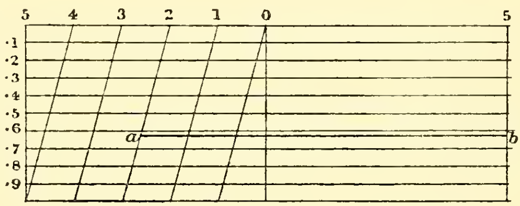
III

OPERATIONS AND PROCESSES OF MAP CONSTRUCTION, OR CARTOGRAPHY

In the two preceding lectures we have considered, first the construction and development of surveying instruments, and then the fundamental principles and methods of geographical surveying. I now propose to tell you something about the construction of the maps themselves from the surveys made as previously described, and to give you an idea of the various operations and processes of map construction, although in a general lecture, such as this, I shall naturally only be able to touch lightly on some of the more important points connected with the subject.

Now, we must begin at the beginning; and the first things to be considered are the scales and projections of maps. The scale of a map is expressed in two different ways: by a fraction such as $\frac{1}{1,000,000}$, $\frac{1}{63,360}$, and so on; or by a linear scale showing miles, kilometres, or whatever measure may have been decided upon for the purpose of measuring distances. The former is called the natural scale of the map, or its representative fraction, marked by R.F., and tells you at once the proportion the map bears to the region it represents; as, for instance, if you saw $\frac{1}{500,000}$ on a map you would know that one inch on the map represents 500,000 inches in nature; or, in other words, if you stretch the map out in all directions to 500,000 times its present size, you would have it as large as the country it represents. Since, then, this is the proportion of the map to nature, this representative fraction is also called the natural scale.

Sometimes several linear scales are given, one of statute miles, and another, perhaps, of kilometres or versts. The form of linear scale from which the most accurate distances can be taken off with a pair of compasses is the diagonal scale. I told you something about this in my first lecture, when I showed an early construction of one for the more exact reading of a circle of an instrument, for which purpose it was occasionally used before the invention of the Vernier. The construction of this is, as you see from Fig. 104, quite simple; in the present case 5 miles are set back from the 0 (zero), on a straight line, and another line is drawn at any convenient distance below this, divided in exactly the same manner. The space between the two lines is divided into ten equal parts; the lines are ruled, connecting these divisions, parallel with the other two lines; the 5 mile divisions on the top and bottom lines are connected by perpendiculars, and then the single miles on the part set back from the zero are connected diagonally. By this means distances to the first decimal of a mile can be read off directly from the scale, and by estimation it is possible to read quite well to the second decimal. For instance, in the example shown, the line *a*, *b* gives the measure of 7·62 miles.



R.F. 1 : 250,000 or 1 inch = 3·95 stat. miles.

Fig. 104.—Diagonal Scale.

For the purpose of comparing one map with another the natural scale is most useful, specially in maps of different nationalities, when different linear measures are employed. For instance, if one map had on it the scale of 1 : 1,000,000; and another 1 : 250,000, we should know at once that the 1 : 250,000 map was four times as large as the 1 : 1,000,000

map; although one might have a linear scale of miles and another one of versts or kilometres.

For this purpose of ready comparison of maps of different nations there is a sort of international agreement amongst geographers to let the 1 : 1,000,000 scale be taken as a standard, and that all other scales, whether smaller or larger, should, as far as possible, be a multiple of ten, so that it will divide into the 1,000,000 an even number of times. It has been decided to construct a map of the whole world on the 1 : 1,000,000 scale in the same style, all the civilized nations taking part in the undertaking. However, many years must elapse before this will be finished, and it will always be subject to revision as fresh surveys are made.

When the natural scale or representative fraction of a map is known, it is easy to find the corresponding linear scale of the number of miles to an inch. There are 63,360 inches in a statute mile, so for a map on the scale of one inch to a statute mile, the representative fraction is 1 : 63,360; therefore, all we have to do to find the number of miles or decimals of a mile to an inch for any map of which the representative fraction is given, is to divide the representative fraction by 63,360.

The scale upon which the map is to be drawn must necessarily depend upon the special purpose of the map, the area to be included, the amount of detail, reliability of the survey documents used, and many other circumstances; but having decided upon this, the next thing to take into consideration is the most suitable projection, and I will now say a few words on this subject of map projections, although as I have many other matters in connection with the production of a map that I want to bring before you, I cannot do more than deal very generally with this somewhat complicated subject.

The earth is *round* and maps are *flat*, so here we are

met with a difficulty at once, for it needs little consideration to see that it is impossible to represent a curved surface on a flat plane, without distortions of some kind, any more than we could take half the rind off an orange and flatten it out without splitting it somewhere. The larger the area the greater the distortion would be. In a small area, such as one degree of latitude or longitude, or less, there will be no appreciable distortion ; but if the map is to include several degrees, the difference between the curved surface and the plane will begin to manifest itself; whilst in the case of a large area, such as a continent or a hemisphere, the distortion must become very serious.

The only correct way of representing the earth's surface is by means of a globe ; but globes would have to be of an enormous size to be really useful for general reference ; so that although they are indispensable for teaching the fundamental principles of geography, the general distribution of land and water areas, and the solution of problems connected with astronomical geography, when we want detail we must turn to maps. A globe giving the whole world on the scale of 1 : 1,000,000, or one inch to 15·78 miles, which, after all, is too small a scale for showing much detail, would have to be something like 135 feet in circumference. This would not be very handy to carry about or to store.

Ingenious persons have tried to produce portable globes by constructing them of indiarubber, oiled silk, and other materials of the kind, so that they could be blown out with air, when in use, like a football ; and deflated or packed away in a flat box or a drawer ; but these have never been really successful, and are only of small size after all. It is true, we might have an atlas consisting of a series of curved maps, all made with a curve struck with the same radius from one centre, so as to form a globe if pieced

together. Such a series was, indeed, commenced by the late illustrious geographer Elisée Réclus; and he left a specimen of this with our Society. These maps would possess certain advantages, and would be an easy way of getting out of the projection difficulty. Still, they would be inconvenient to store, especially if including large areas, and could never be very portable, besides being much more expensive to construct than ordinary maps.

For detailed geographical information we are, therefore, dependent upon flat surface maps, and have to deal with the question of projections as best we can.

We will first take one or two projections of hemispheres,

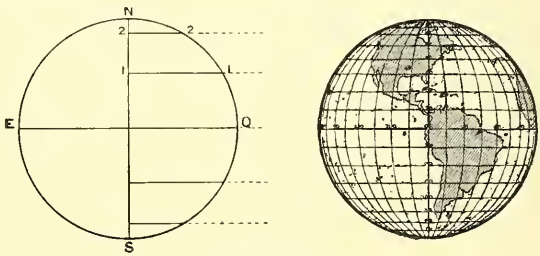


Fig. 105.—Orthographic Projection.

and see upon what principles they are constructed. The one I show you to begin with is called the Orthographic projection (Greek ὀρθὸς, right, and γράφω, to write), and you will understand it by a glance at the diagram (Fig. 105). Suppose the surface of the globe to be transparent, and the plane upon which the projection is to be drawn shown by the line NS; then if we consider the sphere to be viewed at a great distance, so that the rays of light fall on to it as parallel straight lines, we should have the latitude parallels of the surface of the hemisphere projected on to the plane as shown by the figures 1, 2, and it will be seen that whilst these are at equal distances apart on the sphere, they are projected on to the plane in unequal spaces, which

become greatly compressed towards the outer limits of the projection. This projection is not much used for geographical maps, but is occasionally serviceable for showing astronomical problems.

If, instead of the eye being supposed to be at an infinite distance from the sphere, as in the orthographic projection, we imagine it placed on the sphere itself, as at Q in the diagram (Fig. 106), then again, supposing the sphere to be transparent and lines to be drawn from the points 1, 2, etc., on the outer hemisphere, the corresponding points on the plane of projection, NS, would be a resulting projection of the hemisphere, called the stereographic projection (Greek

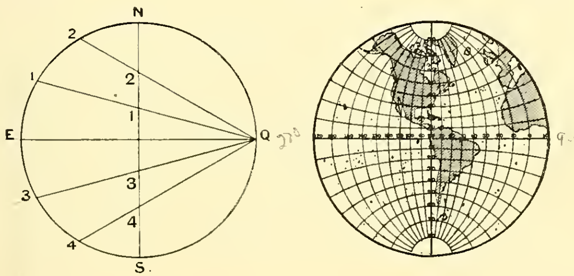


FIG. 106.—Stereographic Projection.

στερεὸς, solid, and γράφω, to write). This would show the great circles passing through the centre of the projection as straight lines, and all the others by circles, or sections of circles, which would be compressed towards the centre of the map, instead of towards the outer circumference, as in the orthographic projection.

In what is usually known as the Globular Projection (Fig. 107) the divisions of the polar axis and equator are made of equal length, and then the circumference meridian is divided into equal divisions of ten or any other number of degrees. Circles of latitude are then made to pass through their proper points on the circumference meridian,

and then through corresponding points on the polar axis and equator. This projection is often used for school maps and atlases, as it gives a more general and even division throughout.

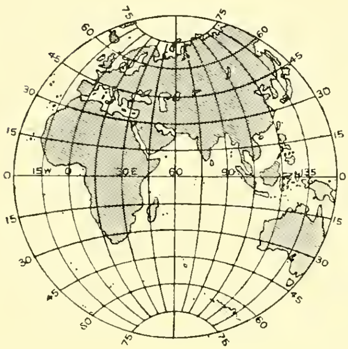


Fig. 107.—Globular Projection.

If instead of supposing the plane of projection to pass through the centre of the sphere, as in the orthographic and stereographic projections, we place it at some position nearer to the eye, as in the diagram (Fig. 108), it is clear that we shall have a projection that will include more than a hemisphere. This is the principle of Sir Henry James's Two-thirds Projection, as it is called, upon which the map showing the arcs of meridians, which I placed before you in the last lecture, was drawn. You will see that two-thirds of the earth's surface is here

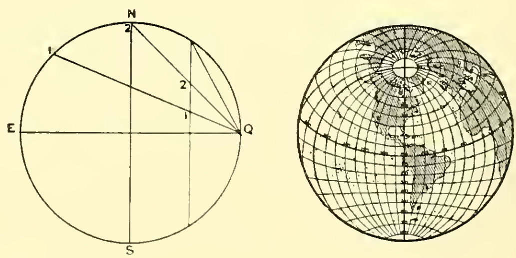


Fig. 108.—Two-thirds Projection.

represented. This is an interesting projection, from the fact that it enables one to look round the other side, so to speak, and see more than half the globe at once. Instead of two-thirds, the projection might of course be made to include any other reasonable proportion of the earth's surface.

I remember drawing a map of this kind once, and a well-known geographer stated that I had made some great mistake, because that while I showed the south pole at the bottom of the map, the North Pole was not at the top, as he considered it ought to be.

Mercator's projection (named after the inventor) is the one almost entirely used for marine charts, for the reason that it is the only one upon which the line of constant bearing can be drawn between any two places as a straight line; so that if a sailor wishes to learn the bearing from one point to another he can find it by drawing a straight line between the two, and reading off the angle this line makes

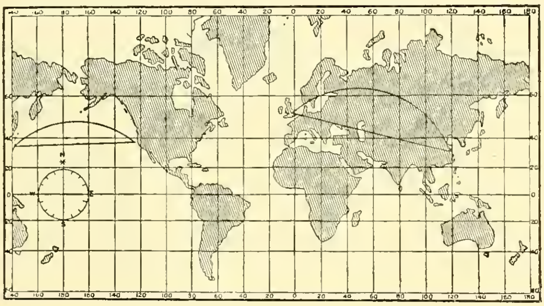


FIG. 109.—Mercator's Projection.

with any north and south line. If he steers his ship on this bearing, he will arrive at his destination, although if the distance be great he will have gone a roundabout way to get there, as you would see if you were to mark off the latitudes and longitudes of the track he has taken on a globe. The shortest distance between any two places is an arc of the great circle. The diagram now before you (Fig. 109) shows the projection of the world on Mercator's projection. The thick straight line, joining the two places, shows the rhumb line, the track the sailor would follow if he kept to the Mercator course, or line of constant bearing; and the curved

line, the arc of a great circle, or the shortest possible distance between the two places. At first sight this seems somewhat hard to believe, but, as I have said, it would be quite clear if you were to plot both tracks on a globe. On the globe, of course, the meridians converge towards the pole, where they all meet. Now, on a Mercator chart the meridians are all shown by parallel straight lines, so if we kept the latitude lines at their proper distance apart, we should see that all

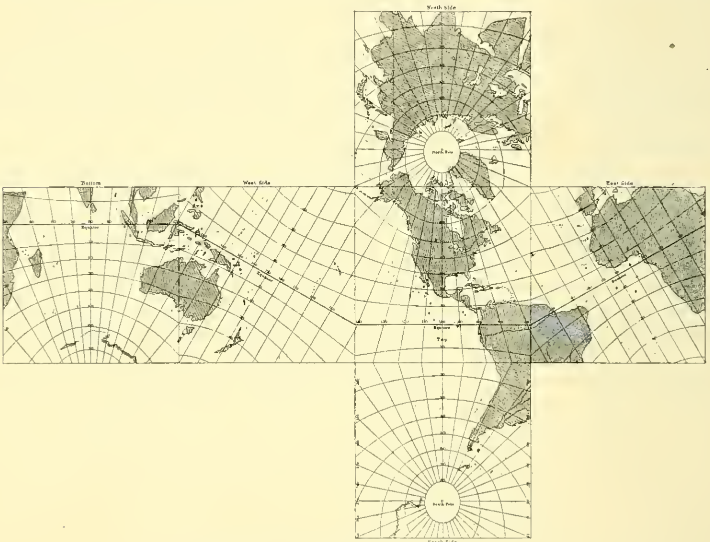


Fig. 110.—Gnomonic Projection.

the land forms would be pulled out in an east-and-west direction, and this distortion would increase more and more the further we got away from the equator. Therefore if we are to preserve the proper forms of the lands, we must increase the distance between the parallels of latitude, just in proportion as we stretch out the meridians to make them parallel lines; so that the latitude lines on a Mercator map get wider and wider apart until they are infinitely distant at the poles. One bad result of this is that it makes all the

land areas away from the equator too large, and this exaggeration becomes enormous near the poles. For this reason the projection is not suitable for educational purposes.

There is a projection upon which great circles between two points can be shown by straight lines : this is called the Gnomonic Projection (Fig. 110), and is best understood by supposing a globe enclosed in a cube, and the outlines of the continents and countries projected from the centre of the sphere on to the six sides of the cube. Charts of the oceans are now often drawn on this projection, so that the navigator can show the great circle course between two points by drawing a straight line between them.

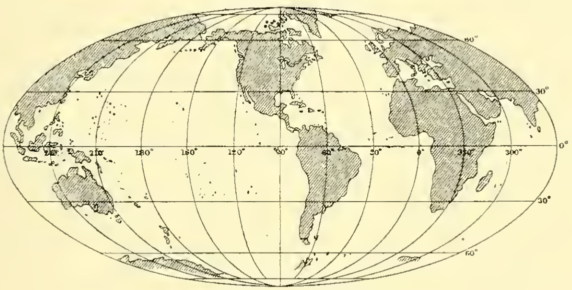


FIG. 111.—Mollweide's Projection.

For the purpose of showing the whole world on one map, an elliptical projection is often useful, of which Mollweide's (Fig. 111) is, perhaps, the best. For exhibiting the distribution of any natural phenomena it is quite useful, and has the advantage of giving equal areas by equal spaces on the map.

Before I say more, I want to show you some drawings for lantern slides I had made some time ago to give an idea at a glance of the exaggerations and distortions of a few of the best-known projections. I may mention that these were made for a lecture to boys; but I will not apologize for showing them, as it is quite possible that there may be some

of us who are older who can more readily appreciate what the shape of the average man's head is than they can the general form of the land masses of the earth. The latitudes and longitudes of all points of the man's head are exactly the same on all the projections, and the remarkable changes in his countenance and the form of his head are entirely due to the different projections used.

Fig. 112.—Globular Projection. This I show first, as you see it is the most generally symmetrical in form.

Fig. 113.—Orthographic projection. Here, as you see, the distortions are all towards the outside circumference.

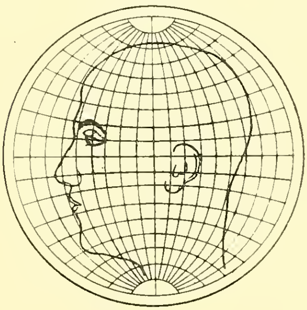


Fig. 112.

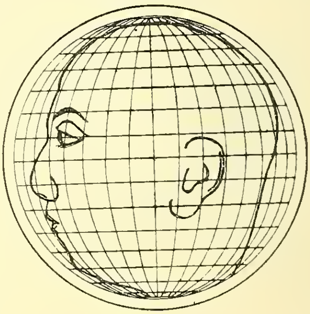


Fig. 113.

Fig. 114.—Stereographic projection. In this the exaggeration is in the other direction, and the map would be squeezed up in the middle.

Fig. 115.—Mercator's projection. From this you will see how absurdly the areas are exaggerated towards the poles.

Since all projections of the sphere must distort or exaggerate in some way or other, a man who is constructing a map has really to make the best of a bad job, and to consider what sort of distortions he can best allow for the special object of his map. Some projections, whilst they pull the form of the continents all out of shape, preserve equal areas, so that say a square inch anywhere on a map,

represents the same number of square miles; these are called "equal area projections"; others called "orthomorphic

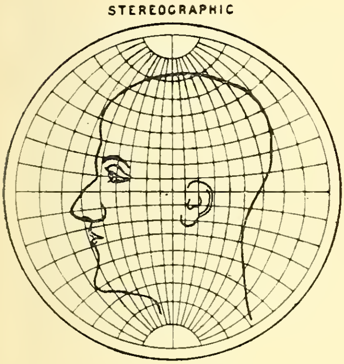


FIG. 114.

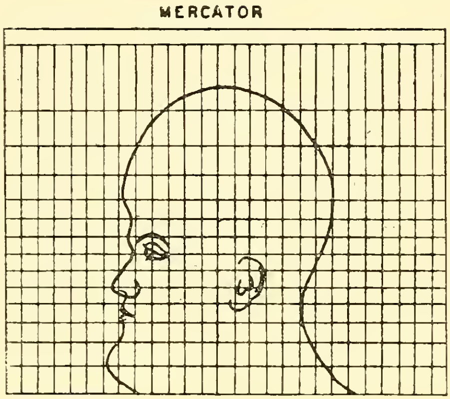


FIG. 115.

projections" give the individual land forms their right shape, but to do this equal area is lost.

For the general representation of a large area, but less than a hemisphere, a continent say, Col. Clarke's minimum error projection is a good one, and Fig. 116 is a map of Africa on this projection taken from Col. Close's excellent text-book on Topographical and Geographical Surveying. This supposes the eye to be over the centre of the area to be represented, and at such a distance that the distortions and errors are, as a whole, the least possible for the area included.

FIG. 116.—Clarke's Minimum Error Projection.

For the mapping of special countries and areas, some

form of what is usually known as the conical projection is generally used; and I will bring my remarks on this part of my subject to a close by a brief reference to these. If we suppose a cone of paper with its apex A (Fig. 117) to touch the earth on the parallel of latitude B, and then the outline of the coast-lines of the globe on either side of this parallel to be drawn on to the paper cone, we should, on cutting the cone down the meridians from A, and flattening it out on a table, have a map of that part of the earth, which would be correct on the centre parallel and less correct as that parallel is left. This is a good projection when there is

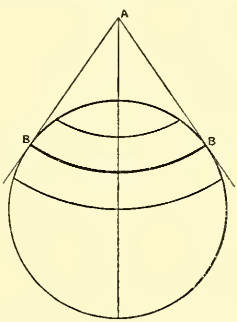


Fig. 117.—Conical Projection.

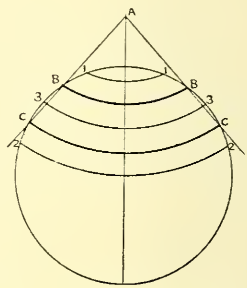


Fig. 118.—Conical Projection with Two Standard Parallels.

very little extent of latitude to be included, but when the latitude ranges over many degrees the errors would be serious at the north and south limits of the map. When this is likely to be the case, another form of the conical projection is used. Suppose we want to construct a map of the part of the zone included between the parallels 1 and 2, with 3 as the central parallel (Fig. 118). Now, instead of the cone touching the central parallel as in the first case, let us suppose that it cuts through the surface of the globe at the parallels B and C; then there will be no errors in the map at these parallels, and the errors in other places will, to a great extent, balance. Instead of constructing the

projection geometrically, the positions for the errorless parallels are generally computed. A very good rule to follow is to compute the positions of the parallels, so that the error on the central parallel shall be equal in amount to that on the limiting parallels 1 and 2. As usually constructed, this projection cannot properly be shown geometrically as in the figure.

There are many other projections which might be described, and the question is a large one ; and although it would be interesting to go more fully into it, in a general lecture this is impossible, so we must now pass on to the other parts of our subject.

Having constructed the projection, we next come to the drawing of the map itself. Maps are of various kinds, and intended to serve different purposes. There are cadastral maps, which have for their special object the marking out on large scales the boundaries of property and estates, generally for fiscal or revenue purposes. There are marine charts, which show with great accuracy everything that would be of importance to the navigator. These naturally do not go far inland, but show the coast-line, landmarks visible at sea, lighthouses, positions of rocks, depths of water, shoals, etc. There are military maps, large plans of special sites, and many others. Then there are general geographical and topographical maps, which are usually on comparatively small scales and cover large areas, and it is to these that we must chiefly confine our attention on this occasion.

A geographical surveyor completes his work in the field, and then returns home with his survey books, records of observations, plane-table sheets, and other information he has collected concerning the region he has visited, and it then becomes the duty of the professional cartographical draughtsman to construct the finished map. To do this work properly he must be competent to check the surveys

and observations, apprize the value of this new work with reference to previous surveys that may have been undertaken in the same region, and to combine the whole into the best possible map. Here a difficulty often occurs at the outset, specially in little-known regions where no triangulation has been carried on, for on comparing this new work with that of other explorers he often finds little resemblance between the two. I have seen maps of parts of Africa, for instance, made from the route surveys of two different travellers, although intended to show exactly the same area, so little like each other that no one would suppose that they were meant to represent the same area had it not been so stated in the title.

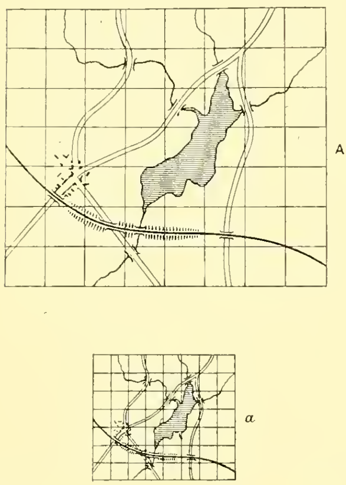
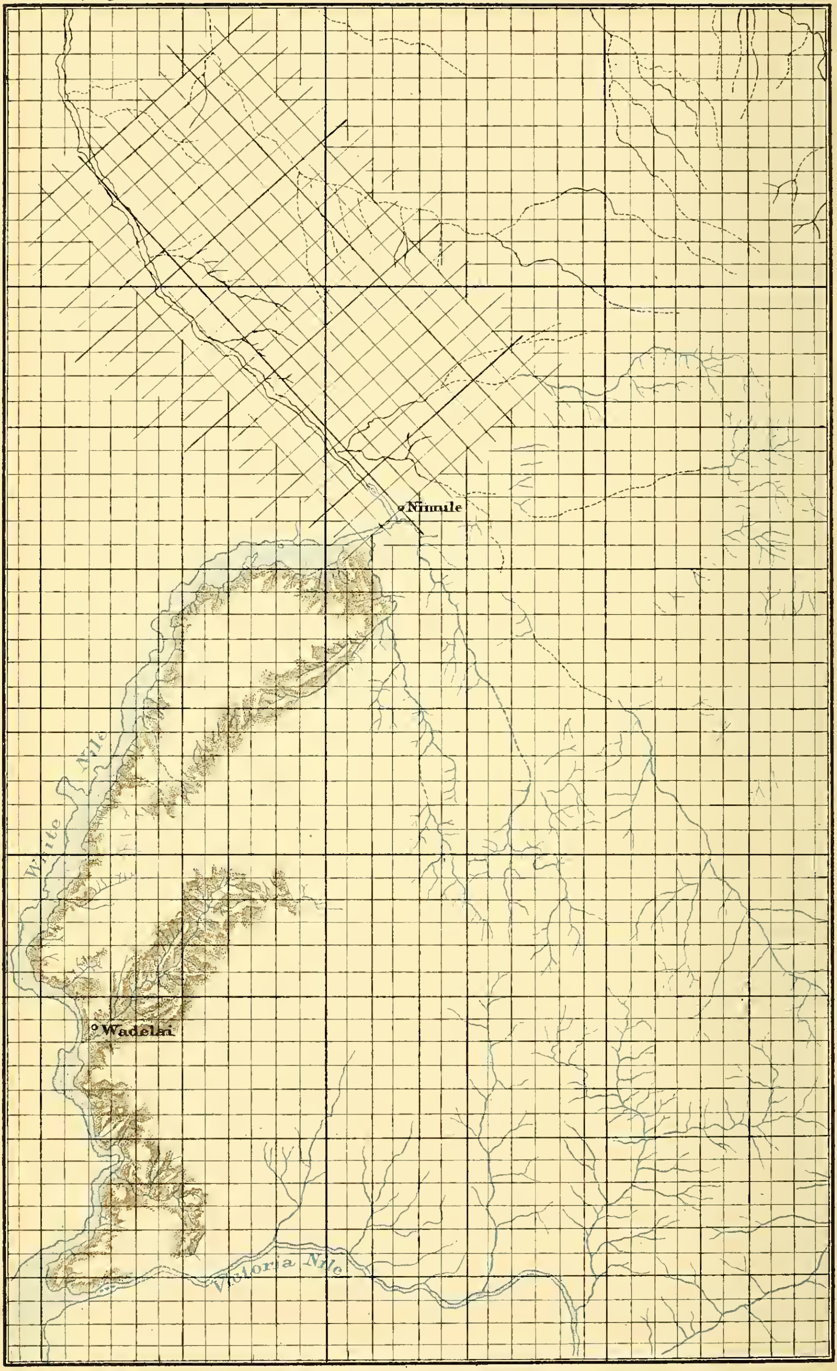


Fig. 119.—Reducing or Enlarging by "squaring in."

When the cartographical material has been sifted and properly arranged, the draughtsman constructs his projection, and places on this, in their exact latitudes and longitudes, the positions of all points that have been definitely fixed by triangulation or astronomical observations. These serve as a foundation for the map, to which plane-tabling, traverses, route surveys, and all other work must be adjusted. The drawing of the map now proceeds in earnest; the various survey sheets and cartographical documents are dealt with one after the other, reduced by a method known as "squaring in," or by some other means, to the scale of the map in hand, upon which each is fitted into its proper place. Here (Fig. 119) is a specimen of "squaring in."

This method consists of ruling each map—the original

 PLATE I



DRAWING OF MAP IN PROGRESS

and the reduction—into the same number of similar squares, and then copying the work in each of the squares on to the corresponding ones on the reduced map. It is well to work from a larger scale to a smaller, if possible, so that errors may be reduced.

I will now show (Plate I., opposite) a map in progress that has reached about this stage, drawn by one of the Society's draughtsmen.

The coast-line and rivers are generally first sketched in pencil, if there is likely to be much alteration later, if not, in fine lines in blue ink. The rivers and streams naturally follow the direction of the drainage of the country, and are a great guide to general features. In drawing the rivers care should always be taken to make a wise selection of the small streams, putting in only as many of the really important ones as is suitable for the scale. Not only the outline of lakes and rivers are shown in blue, but their names also should, in the finished map, be written in this colour, as it is then easy to distinguish them from others.

The representation of mountains and general land relief is naturally a very important matter in map-drawing, and one that calls for a great deal of care and skill to deal with satisfactorily. It is here that, under suitable conditions, a relief map or raised model has the advantage, especially for educational purposes; but if these include a large area of the earth's surface, to show the relief at all, it is generally necessary to exaggerate the vertical scale to such an extent that the result is rather to mislead than to instruct. For large-scale maps of small areas nothing can be better than an accurately constructed relief model. A good example of the kind is a relief map of Palestine in the Society's Map Room, made by Mr. G. Armstrong of the Palestine Exploration Fund from the one-inch Ordnance Survey of Palestine. In this the vertical scale is three and a half times

the horizontal; which is only just sufficient exaggeration to bring out the characteristic features. The Isle of Wight makes another good model, and some excellent ones have been constructed of the Alps. A very fine model of the Alps was shown at the Geographical Exhibition held some years ago in London, which was one of the first results of the excellent work done by our Secretary, Dr. Scott Keltie, in the cause of Geographical Education. However, when we try to show the surface features of a large area on a small scale, or the whole earth in relief, such as has been attempted on a globe in our Map Room, the vertical exaggeration, say of 50 or 100 times the horizontal, is, I feel sure, a mistake. Models are always expensive and awkward things to handle, and in most cases quite impossible; therefore we are compelled to resort to some more or less conventional method of representing hill features.

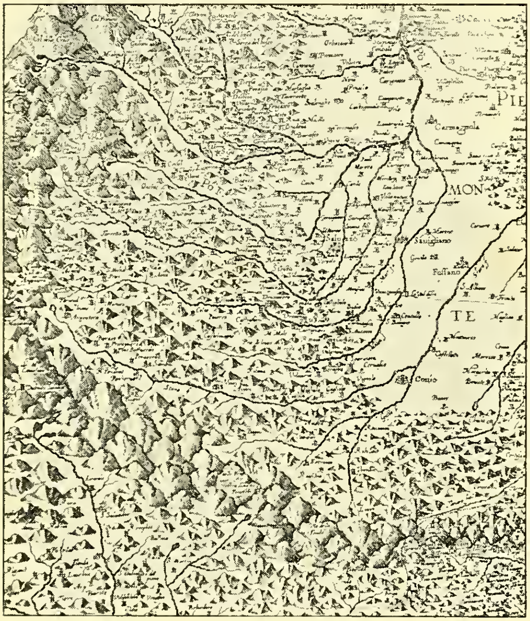


FIG. 120.—Early Method of showing Mountains on Maps.

Doubtless the earliest of all these methods was to draw ranges of mountains and hills in rough perspective. This is exactly what you will find done by primitive people who attempt any kind of map-making to-day.

This system continued in pretty general use till about

the sixteenth century, and the example here given (Fig. 120) is from Magini's map of Italy, 1620. The system was all right in its way, and was certainly picturesque, but, naturally, when accurate maps were required, it had to go. To show mountains like this means, of course, that you can only see one side of the range, and if you want to show a village on the other slope you are done. There were no Ordnance Surveys or Geographical Societies in those days, so the map-maker was left to do pretty much as he liked after all, and he got over the difficulty referred to at times by moving the village away from the mountain into such a position that it could be seen. This would hardly do now, I am afraid.

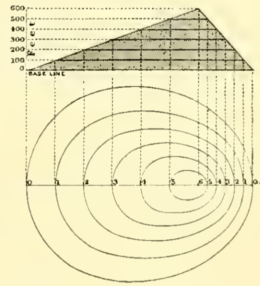


Fig. 121.—Principle of Contouring.

What we have to do, then, is to devise some means of representing relief on a flat surface by vertical projection, or with the eye vertically over the range to be shown. There are various ways of accomplishing this, such as (1) exact contouring, (2) horizontal form lines, (3) brush shading, (4) vertical lines or hachures, as they are called, and (5) colour tinting, commonly called the "layer system." I now propose to show you examples of specimens of each of these.

(1) The most scientific method of indicating relief, is by a system of contour-lines at regular intervals apart, and Fig. 121 shows clearly the principle upon which they are drawn. Fig. 122 is a specimen of a contour map of the Snowdon district, from one of the one-inch Ordnance Survey sheets of England and Wales. These contours are at intervals of 100 feet. Wherever these lines occur the height is accurately known at a glance, and that of any intermediate point can be easily determined by interpolation.

Apart from their accuracy, contours, if sufficiently close, give a good general idea of the relief of a district, as may be seen by Fig. 123. In all exact large-scale surveys contour-lines are accurately drawn from careful levelling, but in more rapid

FIG. 122.—Contoured Map of part of Snowdon District (from 1-inch Ordnance Survey).

work, the lines are only approximate, and are really horizontal form lines. But whether they are proper contours or only approximate, the intervals between them should be in accordance with some rule, which is now, for geographical maps, $\dfrac{50}{\text{inches to a mile}}$.

(2) Horizontal form lines give a very good representation of the relief. They can be quickly drawn, and are nothing

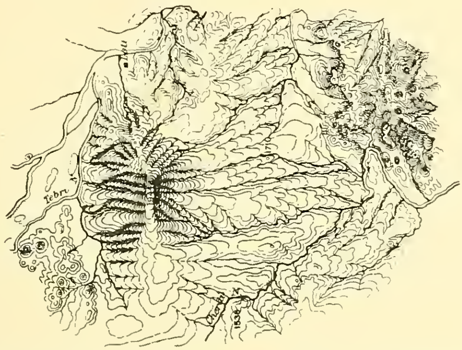


FIG. 123.—Relief Effect given by Close Contour-lines.

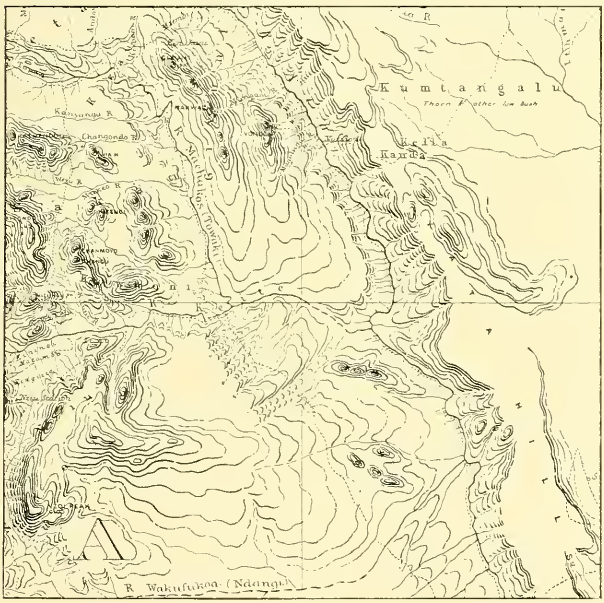


FIG. 124.—Horizontal Form Lines (broken).

like so difficult for a beginner as vertical hachures. There is just the risk of their being mistaken for exact contours, if they are continuous, and for that reason it is often

preferable to break the lines, as is done in the example (Fig. 124).

(3) This map (Fig. 125) is from a drawing by one of our draughtsmen in the brush-shading system of showing hills. Here the light is supposed to fall in vertical rays on to the district, so that if we suppose no diffusion to take place through the atmosphere, the perfectly level parts will

Fig. 125.—Hill Shading (vertical illumination).

appear white; while on the slopes the shading would become darker as their steepness increased, as fewer rays of light would fall on them.

Another system supposes the light to fall at an angle, which in a mountainous region is often very effective in its results, and shows the relief well. Fig. 126 is a specimen of a map of that kind, from one of the excellent coloured

maps of Switzerland. The only drawback to this system is that when there are no contours in addition to the shading one is apt to be misled by the shading, and consider that the lighter slopes are not so steep as the darker, when the only reason for their being lighter is that they are

FIG. 126.—Hill Shading (side illumination), with Contours.

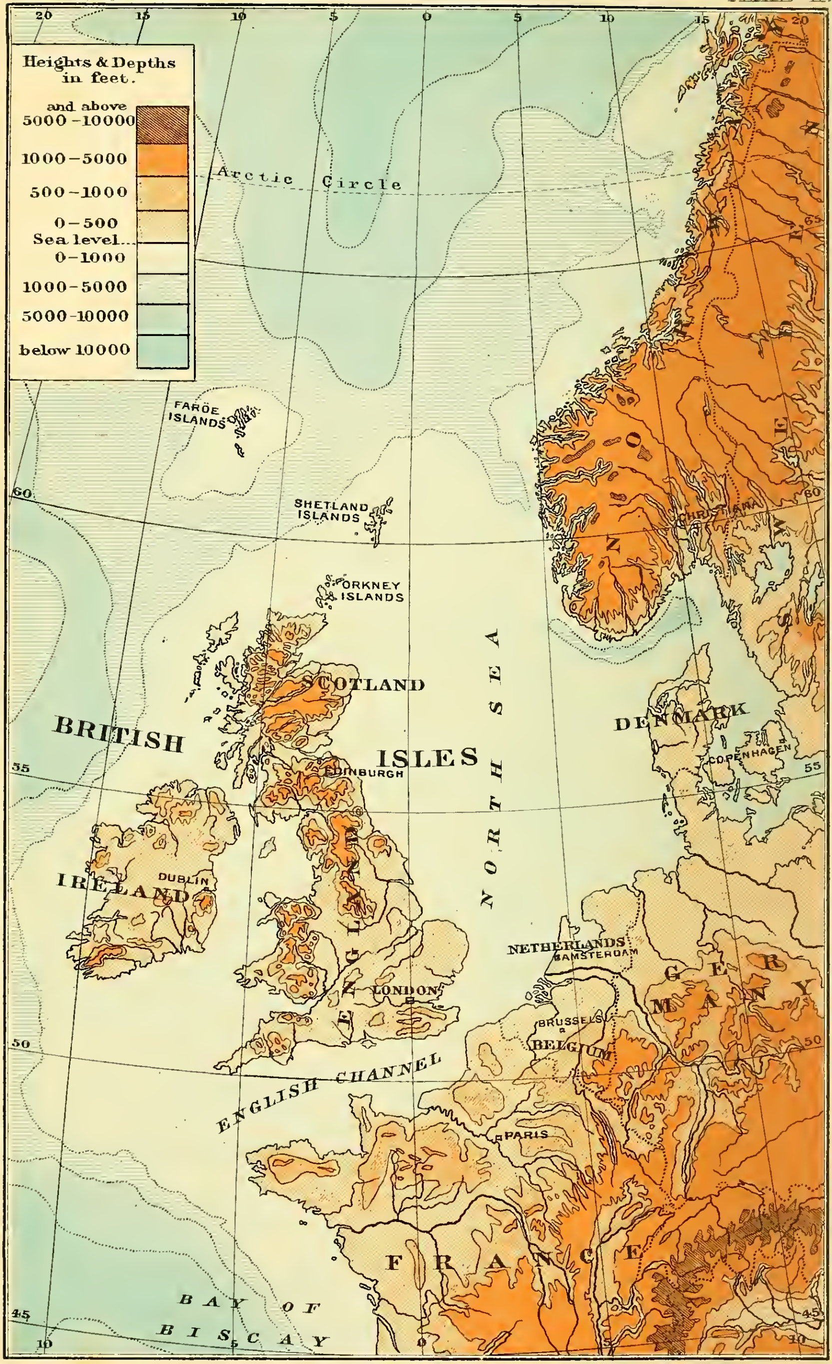
turned towards the light. When this system of shading is employed, it should be combined with contours, as in the present example, in which case there can then be no mistake of this kind.

(4) Fig. 127 is a specimen of the vertical hachure system

of showing hills. Short lines are drawn down the slopes from the crests of the range, following in each case the direction in which streams of water would run. The lines are closer together in steep parts, and become wider apart as the inclination becomes less. For large-scale plans the

FIG. 127.—Hill Shading. Vertical Hachuring combined with Contouring (from Snowdon Sheet of one-inch Ordnance Survey).

intervals are regulated to a proper scale, so many lines going to a certain number of degrees of slope, as you see from Fig. 128, which illustrates the principle. Fig. 127 is, like Fig. 122, from the one-inch Ordnance Survey sheet of the Snowdon area, and shows contours as well. This system



BATHY OROGRAPHICAL MAP. ("LAYER SYSTEM")

is effective when well done, but the drawing of the hachures is a lengthy process, requiring great skill to do satisfactorily.

The old "hairy caterpillar" method of indicating hills (Fig. 129) with which we were familiar in our school days, was, I suppose, a crude attempt at this sort of thing. It is, I am glad to say, now but seldom seen on modern maps.

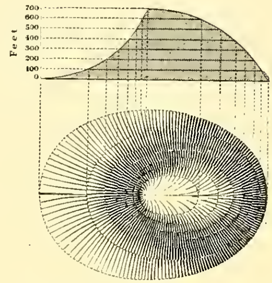


FIG. 128.—Principle of Vertical Hachuring.

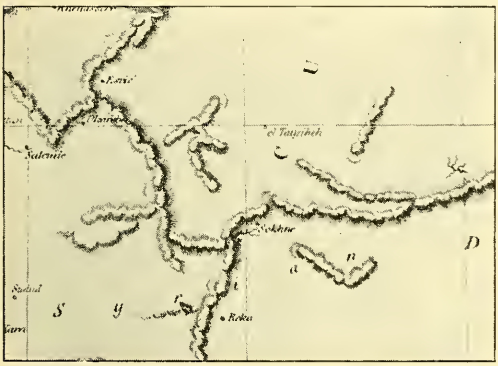


FIG. 129.—Old "Hairy Caterpillar" style of showing Hills.

(*From Findlay's 'Atlas of Comparative Geography,'* 1853.)

(5) I must show (Plate II., opposite) an example of another method of representing relief, generally known as the "layer system." The intervals between certain selected contour-lines are tinted, preferably in shades of one colour, or at any rate in tints that blend well together, which increase in intensity as the altitude increases. All land, therefore, lying between certain altitudes will be shown by one shade, and by reference to the index of the tints, it is easy to fix, within limits, the height of any point. This is a method which has lately come considerably into use in this country, especially for educational and tourist maps, and it certainly possesses many advantages. However, one great objection to the system, certainly from an educational point of view, is that the country appears as a series

of flat steps placed one upon another, instead of the gradual undulations and slopes of which it really consists. Still, much depends upon the execution of the map, and the colours or tints chosen. It is, without doubt, a mistake to introduce an abrupt change in the colours, such as from a dark green to a shade of light brown, since there is no corresponding abrupt change in the configuration of the district itself; besides, to show the low-lying land everywhere as green is often most incongruous. Green, in spite of all explanation that may be given, to most people somehow suggests vegetation, and to show parts of the Sahara, Kalahari, and other deserts in this colour, simply because the land is low, as is often done, is apt to give a wrong impression, especially to children. Wherever possible, it is better to have tints of one colour; or, if sufficient gradations cannot be shown in this way, by shades that blend well together without being strikingly different. Another most important consideration is the selection of the intervals for the tinting, and much of the success of a map depends on this. The intervals should be so chosen that the main characteristic features of the region are clearly brought out. If this is not attended to properly, an entirely wrong impression of the relief of a district may be given, all perhaps through one contour being unwisely selected, instead of another.

Occasionally colour tinting is superimposed upon a map with hills shown by vertical hachures, and this may, if carefully carried out, be successful; but the hill shading underneath, if dark, interferes with the general appearance of the tint above, so that its real character and significance is lost.

The system of selecting the colour tints so that they become darker as the height of the land increases, is, of course, arbitrary, and, although customary, is not altogether

RELIEF SHOWN BY STEREOSCOPIC COLOURING.

satisfactory, as it is after all unnatural, there being nothing in the features of the country to correspond with it. Experiments have, therefore, been made from time to time to improve upon this, and excellent maps have been published lately on a different system. Selecting the prismatic colours, or the shades into which a ray of light is parted in passing through a prism, the red and orange are made to show high lands; then, passing on through bluish-greens and greys, the lowest lands are shown in light greyish-blue. To each of these colours the eyes adjust themselves much as in viewing near and far objects, and if carefully selected, the tints can be made to blend well, and certainly give a striking effect of relief, specially if judiciously combined with hill shading. Plate III., opposite, shows a specimen of this method.

You will have noticed that it is much in this way that a painter gives the effect of nearness and distance to his pictures. In the foreground he introduces red and yellows, and then, for the distances, blues and greys in combination. So here, if a person is supposed to be immediately above the land, the nearest points to his eye would be the mountain-tops, which are reddish-brown, and the furthest away the low valleys, which are bluish-grey. There must, of course, be no abrupt breaks in the colouring. This system of orographical tinting has been called the "stereoscopic" system, for the reason that the effect of relief is somewhat similar to that produced by looking through a stereoscope.

The printing of the tints is naturally costly, as several stones must be used; so, to cheapen the map, sometimes the same kind of effect as that of the layer system is attempted in different symbols or arrangement of lines and dots. This can never be very satisfactory, but if resorted to, the symbols should be so arranged that when viewed generally, without reference to the explanation, there should be a regular

gradation and some appearance of general relief. In the upper map (Fig. 130) this has been entirely lost sight of, and although by close examination we can judge fairly well as to the height of land at any point, as a whole there is no appearance of relief. The lower map, though still only symbols in black are used, gives some idea of relief, as these are arranged so that they become darker as the height increases.

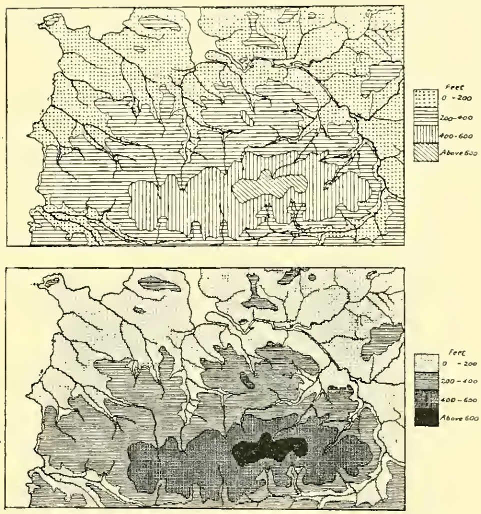


FIG. 130.—Layer System of showing Relief (uncoloured).

To represent the relief of a country at all satisfactorily is by no means an easy matter. Considerable technical skill is required, which only comes after years of training in a geographical establishment. But to become a really successful cartographer, a good deal more is necessary. A man must have an eye for topography. He must also have a knowledge of land forms and physical phenomena which no office or book can teach him, and which can only be acquired by a carefully trained student of nature in the open country, and in the wild domains of Nature herself.

One of the most difficult things in any subject is to generalize, and this is specially so in cartography. To show the leading characteristics of land formation and general physical features of a country without giving undue prominence to comparatively unimportant details, is by no

means easy, and can only be done really satisfactorily by one who has had previous training in geomorphology, and is more or less acquainted with the physical construction of the region he has to map, or at any rate, with some similar region. To illustrate what I mean, I now place before you one or two examples. The map to the left of Fig. 131 is a

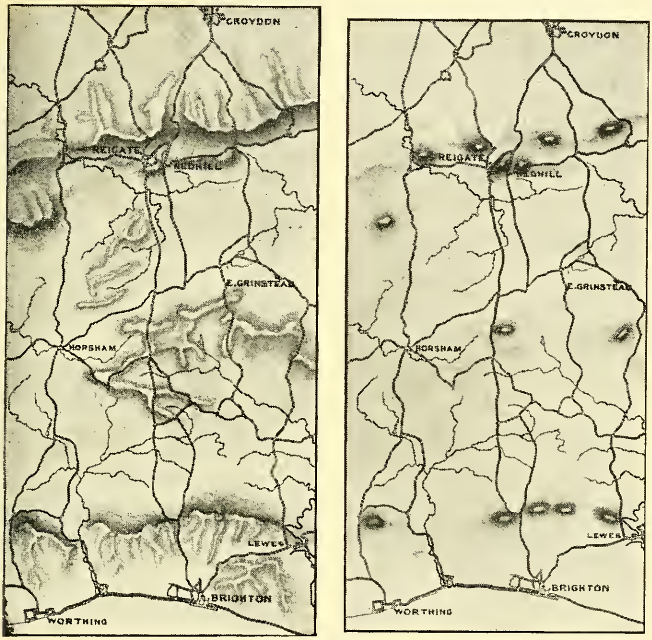


Fig. 131.—Good and Bad Specimens of showing General Relief.

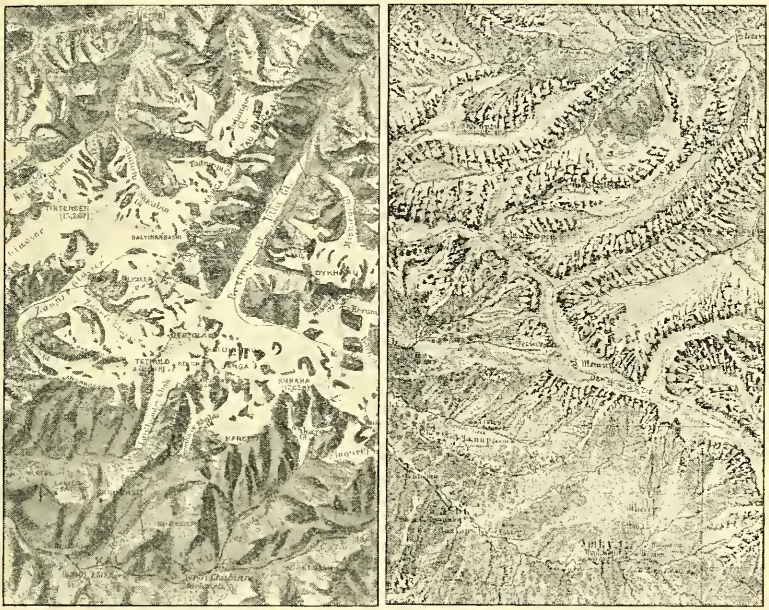
part of the south of England in the neighbourhood of which I reside, taken from the Ordnance Survey. You will see to the north the long chalk range of the North Downs, with their steep escarpment facing south, and the continuous and almost imperceptible slope to the north. Then come the parallel lines of the greensand, and in the centre, the Weald. Towards the south you get the chalk range of the South Downs, with their steep escarpment facing north, the

opposite direction to that of the North Downs. Although these ranges are really continuous, they are broken through in places, and in others higher points appear as hills. A man entirely unacquainted with the district might, therefore, if he finds himself for the first time in certain localities, fail to grasp the characteristic features, and instead of generalizing, give undue prominence to some small hills in his own immediate neighbourhood. This has, indeed, frequently been done by my students in their first attempts, and on the right (Fig. 131) you have the sort of map I have seen drawn of this region. You will see that the man who made this has quite failed to appreciate the general characteristic features of the district ; not only does he represent the hills as isolated and detached, but, forgetting the fact that it is only the escarpment of the North Downs that is in front of him, and that to the north the slope is very gradual, he has shown the northern slopes of this range as similar to the southern.

Many other examples of the kind could be produced to show how important it is that a map-maker should have a general knowledge of land formation and physical phenomena, but I can now only mention one more.

Here (Fig. 132) is a part of the Caucasus range. The map on the right is the region as represented on the old five-verst Russian Government map. Those lake-like forms, filling up some of the valleys between the spurs, are intended to represent glaciers. If you notice, they appear to be perfectly flat, and have no connection whatever with the snow-peaks, or the snow covering the crests of the ridges, which is of course absurd. Although it may be true that at the time this map was made the region had not been properly surveyed, yet this is no reason why the draughtsman should have shown utterly impossible features, which he could not have done if he had previously studied glacial

phenomena in the field. This kind of thing is not restricted to the Caucasus, and I could give you many other similar examples. On the left of Fig. 132 is the same region from the map in Mr. D. W. Freshfield's book on the Caucasus, drawn from the latest one-verst survey sheets of the new Russian survey, combined with information supplied by the author.



From Mr. D. W. Freshfield's map. Same region from old 5-verst Russian Government map.

Fig. 132.—Part of Caucasus Range.

The representation of the orographical features and general relief of a country is such an important matter that I have lingered rather longer than I otherwise should have done on this part of my subject; nor have I now said all I should have liked to on the matter. Still, we must pass on, and I will only add a word or two on the indication of ocean depths.

It used to be the fashion to ignore these pretty much on

physical maps, but really the subject is all one, and the fact of the existence of water should perhaps be looked upon merely as an incident; for mountain ranges, valleys, and plains above the sea-level, visible to the eye, form but a very small part of the general foldings and irregularities of the earth's crust. A good physical relief map should not only show the orographical features, as they are called, but the depths, or bathymetrical features, as well, and this is usually done by contours tinted in blue, increasing in intensity with the depth of the water. This is specially important round the coast-lines of continents and islands. The map (Plate II., p. 129) shows the value of the ocean depths combined with land heights, and indicates clearly the former connection of the British Isles with the continent.

Marine charts are naturally concerned with the oceans and seas, and upon these soundings are indicated in figures; the sandbanks, shoals, rocks, and lighthouses, are carefully placed. Fig. 133 is a specimen of one of our British Admiralty charts. Little attention is, of course, paid to inland features, and only the headlands and prominent points of a coast-line, which serve as landmarks to sailors, are shown.

A very important department of the Admiralty is entirely occupied with marine surveys, and the constructing of these charts, of which continual revision is necessary, owing to changes in sandbanks in the sea-bed, caused by silting, earthquakes, and volcanic eruptions, so that fresh surveys are always being called for. To a great extent the safety of navigation depends upon the Hydrographical Department of the Admiralty, and if the public really knew how much they are indebted to it, they would feel good reason to be proud of it and the work it is doing.

Although the Ordnance Survey maps of the British Isles have always been held in great esteem for their

accuracy and excellent execution, during the last fifteen years or so improvements in several respects have been made in the style of production, specially with the one-inch and other smaller scales. Doubtless the most important of these is the introduction of colour in the printing, which has added in no small degree to their clearness and legibility. The Government survey maps of several continental countries,

FIG. 133.—Part of Admiralty Chart of English Coast.

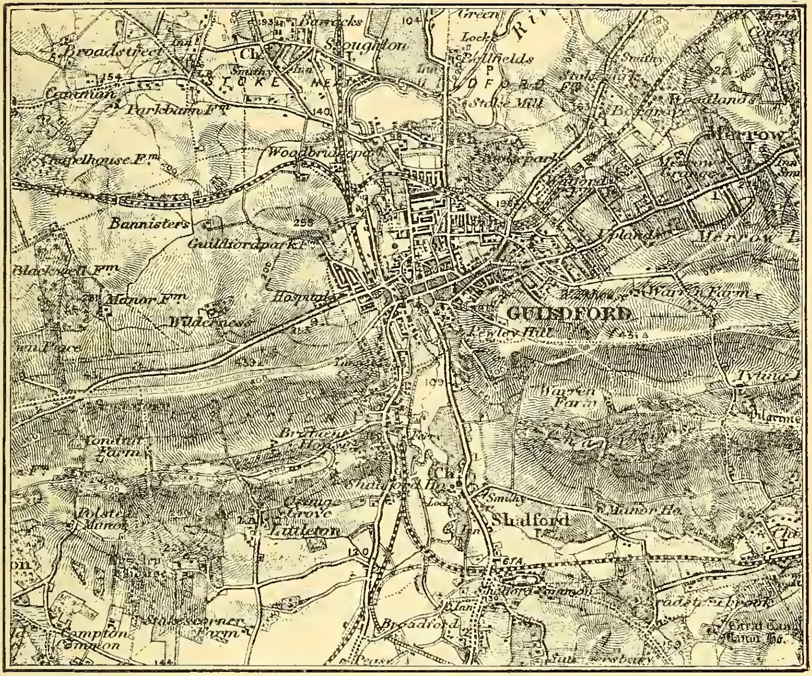
such as France and Switzerland, had been printed in colours long before our own maps, and I well remember the time when there was no such thing as a coloured sheet of the Ordnance Survey to be obtained. In 1892, owing to influential representations, in which this Society should ever remember that Mr. Douglas W. Freshfield, then one of our Honorary Secretaries, took a leading part, a Committee met to consider the matter, and the then Director of the

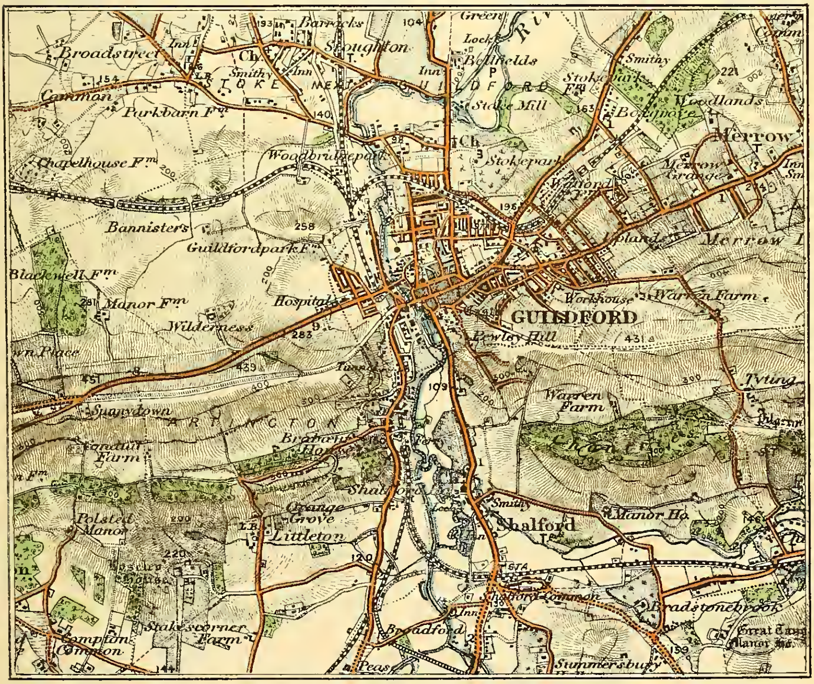
Survey and others concerned, entered in a most whole-hearted way into the suggested alterations in the style of printing, with the result that, after most careful experiments, we have to-day coloured maps which compare most favourably with those of any other country, and are a great advance upon the early black and white sheets.

The usual, and perhaps best colours now employed in map printing are brown for contours or hill shading, blue for water, green for wooded lands, reddish-brown for roads or routes, and black for lettering and outlines. Here (Plate IV., opposite) is a part of the 1-inch sheet of the Guildford district in black, and below it, coloured as described, and I feel sure that you will all agree that the introduction of the colouring is a vast improvement.

Roads, paths, railways, canals, and rivers, with the limit of their navigability, should all be most clearly shown on maps intended for general reference, and this is usually done now by different colours and symbols, explanations of which should be clearly printed on each sheet of the map. As regards roads and paths, it is important that their breadth, general character, and the traffic for which they are suitable, should be indicated. Legal questions often arise with reference to the public right of way, so that it may be impossible, or at any rate inadvisable, to attempt to indicate whether the road or path is public or private.

Important though these large-scale survey maps of civilized countries always must be, we, as Fellows of the Royal Geographical Society are perhaps, after all, more interested in the maps and mapping of the less-known and more approximately surveyed regions of the earth. I therefore invite your inspection of some specimens of geographical and topographical maps constructed on approved lines, published either in this Society's *Journal*, or by that most excellent branch of the War Office called the Geographical Section,





PLAIN AND COLOURED 1 INCH ORDNANCE SURVEY MAP

which, under the able superintendence of Lieut.-Colonel C. F. Close, R.E., C.M.G., who, I am glad to say, is now one of our Honorary Secretaries, has made such rapid strides, and is doing really wonderful work in the mapping of hitherto unmapped parts of the world, especially of the outlying parts of our own Empire. If any of you are thinking of becoming travellers, and want to know the kind of map we wish to produce from your work, you cannot do better than inspect the specimens of these, which you will find in the Society's Map Room. I propose to finish this lecture with a few remarks on engraving, lithographing and printing of maps, but before dealing with these matters, there is one other subject which I must not overlook, and that is the question of nomenclature and place-names generally.

In early days, and in fact not so many years ago, it was quite the custom for explorers to give pretty much what names they liked to places they discovered, and to spell these and any others, every man according to his special fancy. Consequently all sorts of confusion arose. A man who wished his own name, or the name of some intimate friend, handed down to posterity, would fix it on to a mountain or river, or if not the name of a person, some fanciful name of his own invention. Another traveller, coming along, who had never heard of this, would call it after some one or something else, neither of them taking the trouble to find out if it had a name already by which it was known to the natives. Now all this is altered, and no one who is worthy of the name of an explorer would think of fixing names to places without first studying the rules laid down by this Society. As for personal names, this is never encouraged, and in no case must they be given unless, after long and patient research, it is found that no native name exists. This is perhaps hardest on the lady friends whom the traveller leaves at home, and who were in times past

often in measure consoled for the long parting by seeing their names in print on a map.

Apart from the spelling, the question of the names to be placed on the maps is a large one. So much depends upon the purpose of the map, the scale, and other circumstances. An educational physical map intended to show natural features, should of course have very few names, and such as it may be considered absolutely necessary to give should be printed in light ink, or in some manner that does not obliterate or tend to confuse the physical features. On maps intended for general reference, the names should be clear, and such maps should not attempt to do more than lightly indicate leading physical features. Often on small-scale maps it is better to leave out hill shading altogether.

As a general rule no name should appear on a map without there being a direct reason for its existence.

Many ridiculous mistakes have, in the past, often been made in the naming of places in regions explored for the first time through the explorer not being acquainted with the native language. For instance, a man asks a native, as best he can, what the name of a certain peak is, and the native, failing to understand the question, asks in his own tongue, "What did you say?" The traveller is pleased, as he thinks he has got the name, and without further questioning chooses the spelling that to his ear best expresses the sound of the reply, and the mountain appears on the map as, "Mount What did you Say." Many cases of this sort of thing exist, and if afterwards the mistakes are discovered, it is almost impossible to get them removed from the maps. One map is copied from another, and so it goes on year after year. The following will show how easy it is for absurd mistakes in names of places to occur. The draughtsman had a proof of a chart submitted to him, and first made an alteration, but afterwards, finding his first spelling was

right, he placed "Stet" at the side to show that no alteration was to be made. However, the intelligent lithographer put "Stet" down on the chart as a new place, and it was only after long searching for this place in the region without success that the mistake was discovered.

Up to the beginning of the fifteenth century, the only method by which maps could be reproduced was by the

FIG. 134.—Specimen of Early Printed Map.
(From the edition of Ptolemy, Rome, 1478.)

slow and expensive process of hand copying. The introduction of metal and wood engraving, although perhaps of a much earlier date in the East, appears to have taken place in Europe about A.D. 1406, and what may be considered among the earliest printed maps are those given in the edition of Ptolemy, published at Rome in 1478. Fig. 134 is a facsimile of one of these interesting old maps. After

this date metal and wood engraving became quite ordinary methods of map reproduction, and gave a tremendous impetus to the study of geography. Several editions of Ptolemy's geography were published with engraved maps, and many other interesting cartographical specimens appeared.

From the latter half of the fifteenth century until towards the close of the eighteenth century, nearly all maps were engraved by some means, but in the year 1771, Sennefelder of Prague hit upon, more by accident than anything else, the method by which far the greater number of maps are reproduced at the present time, that is lithography. To engrave a map by hand, whether on copper, wood, or anything else, is a most lengthy process, and requires great skill; but by means of lithography, hand-engraving can be entirely obviated. The story of Sennefelder's discovery is most interesting, and is probably known to most of you. Having been asked by his mother to make out a bill for her, and having no other material upon which to write at hand, he wrote it on a flat smooth piece of stone which he was using for another purpose, the ink being composed of wax, soap, and lampblack. When about to wash the bill off the stone, it struck him to cover its surface with a mixture of aqua fortis (nitric acid) and water, of which the proportions were one of the acid to ten of water, and after doing this he found that the lines of writing stood up slightly above the surface of the stone, which had been eaten into by the acid. Here, then, was a method of engraving without the long tedious process of hand cutting. It was a grand discovery, and one which was destined very soon after to entirely revolutionize the method of printing, and was specially suitable to the reproduction of maps and plans.

The method which in such a remarkable manner was

suggested to Sennefelder, has, of course, been improved upon since his time, but in principle it is the same to-day. Fine-grained sandstone of special texture and quality, of which the best comes from Bavaria, is cut into slabs, and upon the smooth surface of this lithographic stone the map is drawn by a lithographer in the reversed way to that of the original drawing furnished him by the geographical draughtsman. The drawing on the stone is made with a special ink, composed of tallow, wax, soap, shellac, and fine Paris black. The stone is now damped with water or a composition of acid and water, and then if the roller with greasy ink is made to pass over the stone, a sheet of paper pressed upon the stone afterwards, will only take the impression of the lines previously drawn. By continually rolling with ink, thousands of copies can be printed off in this way. The principle really depends upon the antagonistic qualities of grease and water.

Instead of stone, sometimes zinc sheets are used, as they are cheaper and handier to store, but the work is then generally of a somewhat coarser nature.

Hill shading is frequently done on stone by a process called chalking. A crayon or pencil is made of hard lithographic ink, and then the shading is done on a grained stone, from which copies are printed off in the usual manner.

It is not an easy matter to draw a map on stone, specially as the whole thing has to be drawn the reverse way, and the lettering written the wrong way about. A good lithographer who can produce a first-rate map is a valuable man.

To obviate the difficulty of drawing on the stone, a more rapid and straightforward method is now frequently resorted to. This is the transfer method, and consists of drawing the map in the ordinary way on special tracing

paper with greasy transfer ink. This drawing is afterwards placed, face down, on the stone, and being pressed upon it by a roller, leaves an impression. The stone is then treated as before, inked rollers being passed over it, and copies printed off in the usual manner.

In photo-lithography, a photographic negative on glass is taken of the drawing in lines or dots. The negative is then put into a photographic printing frame, and a piece of sensitive transfer paper placed face downward upon it, the glass side being exposed to the light. After exposure it is taken into a dark room, the photographic print taken out of the frame, laid face downwards on a stone, coated over with transfer ink, and pulled through the press. It is then soaked in warm water, and the inked side of the paper carefully sponged in gum water to remove the ink from the parts upon which the light could not act. After being washed in warm water it is allowed to dry, and is transferred to the stone, and copies are printed in the usual manner.

There is no doubt that the best of all methods for producing really fine cartographical work is engraving, but it is very expensive. Here the outline, writing, and all that is really important, is cut by a gravure on copper plate or stone, and finer work can be produced in this way by a skilful man than by any other.

The trouble about coloured maps is, that every separate colour means a separate stone and separate printing, which entails a great deal of extra time and expense. Certain combinations of colours can be printed from one stone, but the maps you see in the *Geographical Journal* with brown hills, red routes, blue rivers and black writing, mean four different stones, and the extra cost for printing each stone means for, say, 6000 copies, about £5 ; so you see it becomes quite a serious matter to have many separate colours on a map. After the copies have been printed off, in order to preserve

the surface of the stone for use on a future occasion, it is covered with a coating of gum.

The cost of the lithography and printing of a good coloured map in the *Geographical Journal* may be anywhere between £25 and £60, and for very large special maps, even much more. There is a fine opening for an inventor who can hit upon some really practical way of printing different colours from one stone.

Folded at the end is given, as an example of the recent cartographical work of our Society, the map of the results of the Uganda-Congo Boundary Survey, under the command of Lieut.-Colonel R. G. T. Bright, C.M.G., which was published in the *Geographical Journal* for last year.

THE END

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